# Bacteria TMDL for Flat Creek
# Mecklenburg County, Virginia

**Submitted by**

**Virginia Department of Environmental Quality**

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# Executive Summary


This report presents the development of a Bacteria Total Maximum Daily Load (TMDL) for the Flat Creek watershed. The Flat Creek watershed is located in Mecklenburg County in the Roanoke River Basin (USGS Hydrologic Unit Code 03010106). The waterbody identification code (WBID, Virginia Hydrologic Unit) for Flat Creek is VAC-L79R-01 in the Piedmont region of Virginia.

The impaired segment is 8.95 miles in length beginning upstream at the South Hill Regional Sewage Treatment Plant discharge, and extending downstream to the Roanoke River (Lake Gaston).

The drainage area of the Flat Creek watershed is approximately 29.51 square miles. . The average annual rainfall as recorded at the John H. Kerr Dam, Virginia (approximately 10.0 miles southwest of study area) is 38.55 inches. The approximately 18,917-acre watershed is predominately forested (60.0 percent). Agriculture encompasses 30.74 percent of the watershed, with 2.94 percent cropland and 27.8 percent pasture/hayland. Residential and high use industrial areas compose approximately 1.25 percent of the land base. Transitional areas account for 0.69 percent of the land use. The remaining 6.43 percent of the watershed is comprised of wetlands and open water.

Flat Creek was listed as impaired on Virginia’s 1996 and 1998 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1996 & 1998), and on Virginia’s 2002 303(d) Report on Impaired Waters (VADEQ, 2002) due to violations of the State’s water quality standard for fecal coliform bacteria and the General Standard (benthic). Out of 24 bacteria samples collected during the 1996 assessment period, 7 violated the water quality standard. During the subsequent 1998 assessment period, 17 of 59 samples violated the water quality standard, and during the most recent 2002 assessment period, 12 of 57 samples violated the standard.

According to Virginia Water Quality Standards (9 VAC 25-260-10A), “all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish).”

As indicated above, Flat Creek must support all designated uses and meet all applicable criteria. Flat Creek does not currently support primary contact recreation.

The load-duration approach is used to develop the TMDL for the study watershed.

The assessment of bacterial sources involves estimating loads from various sources in the watershed. It was accomplished by determining the relative contribution by these sources using Biological Source Tracking (BST) methodology. A total of 12 ambient water quality samples were collected on a monthly basis from September 2002 through September 2003 for BST analysis. The results indicate that the majority of bacteria are coming from anthropogenic sources. Four categories of sources were considered: human, pet, livestock and wildlife. The analyses determined the relative contribution of all bacteria by these sources. The data indicated that on an average basis, relative contributions of bacteria are – 11% by human, 29% by pet, 43% by livestock, and 17% by wildlife. Fecal and *E. coli* bacteria were also enumerated as part of the BST analyses.

The bacteria loads in the study watershed were calculated for point source and non-point sources. The study area has one sewage treatment plant having an average discharge ranging from 0.475 million gallons per day to 1.23 million gallons per day (MGD). The flows are within DEQ’s permitted level of 2.0 MGD. The permitted loads were calculated by multiplying the permitted discharge concentration (126 cfu/100 ml) times the permitted flow times the appropriate unit conversions. For non-point sources (human, pets, livestock, and wildlife) total annual fecal productions were calculated separately. Data on population density and waste production by septic systems, pets, livestock and wildlife were collected from various sources, and total fecal productions were calculated with appropriate unit conversions.

The load-duration method essentially uses an entire stream flow record to provide insight into the flow conditions under which exceedances of the water quality standard occur. There was no gaging station on Flat Creek; therefore, the flow-duration curve using historical flow data collected at the USGS gaging station Allen Creek near Boydton, VA (#02079640) was developed. The load-duration curve for Flat Creek was then developed by multiplying each flow level along the flow-duration curve by the applicable water quality standard and required unit conversions. Each water quality observation is then assigned to a flow interval by comparing the date of each water quality observation to the flow record of the reference stream. The stream flow from the date of the water quality observation is then used to calculate a stream flow and flow-duration interval for the stream. The loads on the load-duration curve are multiplied by 365 days/year to determine the annual loads. Fecal coliform data was converted to E. Coli using a translator equation developed based on the data sets from the DEQ's statewide monitoring network. The observed loads were plotted on the load-duration curve to determine the number and pattern of exceedances of water quality standards.

The results indicated that the highest exceedance of the water quality standard occurred at a normal flow that has been exceeded approximately 52% of the time (~2 cfs). This represents the flow condition under which the largest bacteria reduction is required in order to meet water quality standards. The translated load at this flow condition is $7.24 \times 10^{14}$ cfu/yr. At the average annual flow condition, this load would be $7.17 \times 10^{14}$ cfu/yr. To meet the of instantaneous *E. coli* water quality standard of 235 cfu/100mL, this load would have to be reduced by 99.5% to an allowable load $3.66 \times 10^{12}$ cfu/yr. The allowable load is simply the *E. coli* standard multiplied by the applicable flow condition and the proper unit conversions.

For the Flat Creek watershed, the average annual *E. coli* load is $7.17 \times 10^{14}$ cfu/yr, and the TMDL under average annual flow conditions is $3.66 \times 10^{12}$ cfu/yr. These values are used to calculate required reductions. By subtracting the waste load allocation (known value) from the TMDL (as computed), and the implicit margin of safety, the load allocation was determined. These values are presented in the following Table.

**Table E1. Average annual *E. coli* loads and TMDL for the Flat Creek watershed (cfu/yr)**

| WLA[1] | LA | MOS | TMDL |
|---|---|---|---|
| $3.48 \times 10^{12}$ | $1.8 \times 10^{11}$ | (implicit) | **$3.66 \times 10^{12}$** |

[1] The point source permitted to discharge in the Flat Creek watershed is presented in section 5.2.

Sanitary Sewer Overflows (SSOs) result in the discharge of untreated wastewater into Flat Creek and its tributaries. In older sections of South Hill, terra cotta sewer lines frequently break or become blocked by grease and other debris.

For Flat Creek, the WLA represents 95% of the TMDL load. The required reduction of 99.975% is to be applied to each of the four non-point sources identified in the BST analysis.

The Flat Creek TMDL development presented in this report is the first step toward the attainment of water quality standards. The second step is to develop a TMDL implementation plan, and the final step is the field implementation of the TMDL to attain water quality standards.

The Commonwealth intends for this TMDL to be implemented through a process of phased implementation of best management practices (BMPs). The development of the Flat Creek TMDL requires a 99.975% reduction in non-point source loading in order to attain a 0% violation of water quality standards. In order to evaluate interim reduction goals for a phased implementation plan, several reduction levels (80%, 70%, and 60%) and their associated violation rates were assessed. Reduction curves similar to the maximum exceedance/reduction curve were plotted and are presented in this report.

Results also indicate that approximately 59% of the violations occurred during times of precipitation or just after a precipitation event. This suggests that those violations could be related to runoff events. Among some of the BMPs effective in reducing bacteria runoff from such precipitation events include riparian buffers zone, retention ponds/basins, range and pasture management, and animal waste management. Detailed lists of BMPs and their relative effectiveness will be included in the eventual TMDL implementation plan for the watershed.

The development of the Flat Creek TMDL would not have been possible without public participation. A public meeting was held in South Hill, Virginia on October 20, 2003 to discuss the process for TMDL development and the source assessment input. Twelve people attended the meeting. Copies of the presentation materials and the draft TMDL report were available for public distribution. The meeting was public noticed in the Virginia Register. There was a 30 day-public comment period and no written comments were received. A second public meeting was held in South Hill, Virginia on March 16, 2004 to discuss the results of the TMDL development and the source assessment. Nineteen people attended the meeting. Copies of the presentation materials and the draft TMDL report were available for public distribution. The meeting was public noticed in the Virginia Register. There was a 30 day-public comment period and no written comments were received.

# 1. Introduction

Section 303(d) of the Clean Water Act and US Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies which are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and non-point sources to restore and maintain the quality of their water resources (EPA, 1991).

The Commonwealth of Virginia's (Virginia's) 1997 Water Quality Monitoring, Information, and Restoration Act (WQMIRA) codifies the requirement for the development of TMDLs for impaired waters. Specifically section § 62.1-44.19:7 C states:

*"The plan required by subsection A shall, upon identification by the Board of impaired waters, establish a priority ranking for such waters, taking into account the severity of the pollution and the uses to be made of such waters. The Board shall develop and implement pursuant to a schedule total maximum daily loads of pollutants that may enter the water for each impaired water body as required by the Clean Water Act. "*

The EPA specifies that in order for a TMDL to be considered complete and approvable, it must cover the following eight elements:

1. It must be designed to meet applicable water quality standards,
2. It must include a total allowable load as well as individual waste load allocations and load allocations,
3. It must consider the impacts of background pollution (in the case of Flat Creek this is wildlife),
4. It must consider critical environmental conditions or those conditions (stream flow, precipitation, temperature, etc.) which together can contribute to a worst-case exceedance of the water quality standard,
5. It must consider seasonal variations which together with the environmental variations can lead to a worst-case exceedance,
6. It must include an implicit or explicit margin of safety to account for uncertainties inherent in the TMDL development process,
7. It must allow adequate opportunity for public participation in the TMDL development process,
8. It must provide reasonable assurance that the TMDL can be met.

The following document details the development of a bacteria TMDL for Flat Creek, which was listed as impaired on Virginia's Impaired Waters List in 1996, 1998, and 2002. Approximately 8.95 miles of Flat Creek were listed as impaired due to a violation of Virginia's water quality standard for fecal coliform bacteria.

A glossary of terms used throughout this report is presented as Appendix A.

# 2. Physical Setting

## *2.1. Listed Water Bodies*

Flat Creek is located in Mecklenburg County in the Roanoke River Basin (USGS Hydrologic Unit Code 03010106). The waterbody identification code (WBID, Virginia Hydrologic Unit) for Flat Creek is VAC-L79R-01. The impaired segment is 8.95 miles in length beginning upstream at the South Hill Regional Sewage Treatment Plant discharge, and extending downstream to the Roanoke River (Lake Gaston). The Flat Creek watershed is outlined (Figure 1).

**Figure 1. Map of the Flat Creek study area**

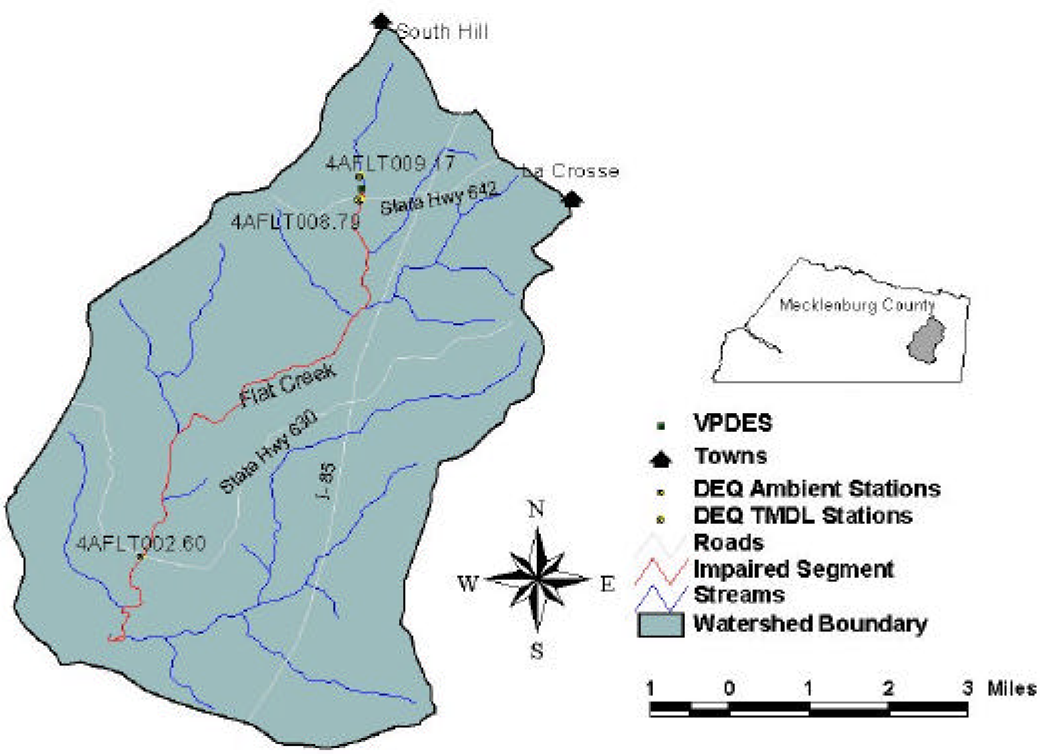


**Table 1. Impaired segment description (Flat Creek)**

| Segment (segment ID) | Impairment (source of impairment) | Upstream Limit Description | Downstream Limit Description | Miles Affected |
|---|---|---|---|---|
| Flat Creek (VAC-L79R-01) | Fecal Coliform (NPS – Agriculture) | South Hill Regional Sewage Treatment Plant discharge | Confluence with Roanoke River (Lake Gaston) | 8.95 |

## *2.2. Watershed*

### 2.2.1. General Description

The Flat Creek watershed is located entirely within Mecklenburg County, Virginia. The Flat Creek watershed runs in a southwesterly direction. The watershed is approximately eight miles long and 3.7 miles wide, having an area of approximately 29.51 square miles.

Flat Creek flows southwest from its headwaters near South Hill, Virginia, to its confluence with the Roanoke River (Lake Gaston). The Roanoke River eventually discharges into the Albemarle Sound.

### 2.2.2. Geology, Climate, Land Use

***Geology and Soils***

Flat Creek is located in Mecklenburg County within the Piedmont physiographic province. Topography varies slightly in the watershed, with elevations above sea level ranging from 61 (200 ft) to 142 (466 ft) meters (Figure 2). Major soil groups in the region are shown in Figure 3 using the State Soil Geographic (STATSGO) Database (STATSCO, 1994). In general, the soils of the Flat Creek watershed are moderately permeable with medium to rapid runoff rates. The soils tend to be well suited for general development, septic systems and agriculture.

**Figure 2. Elevation profile of the Flat Creek watershed**

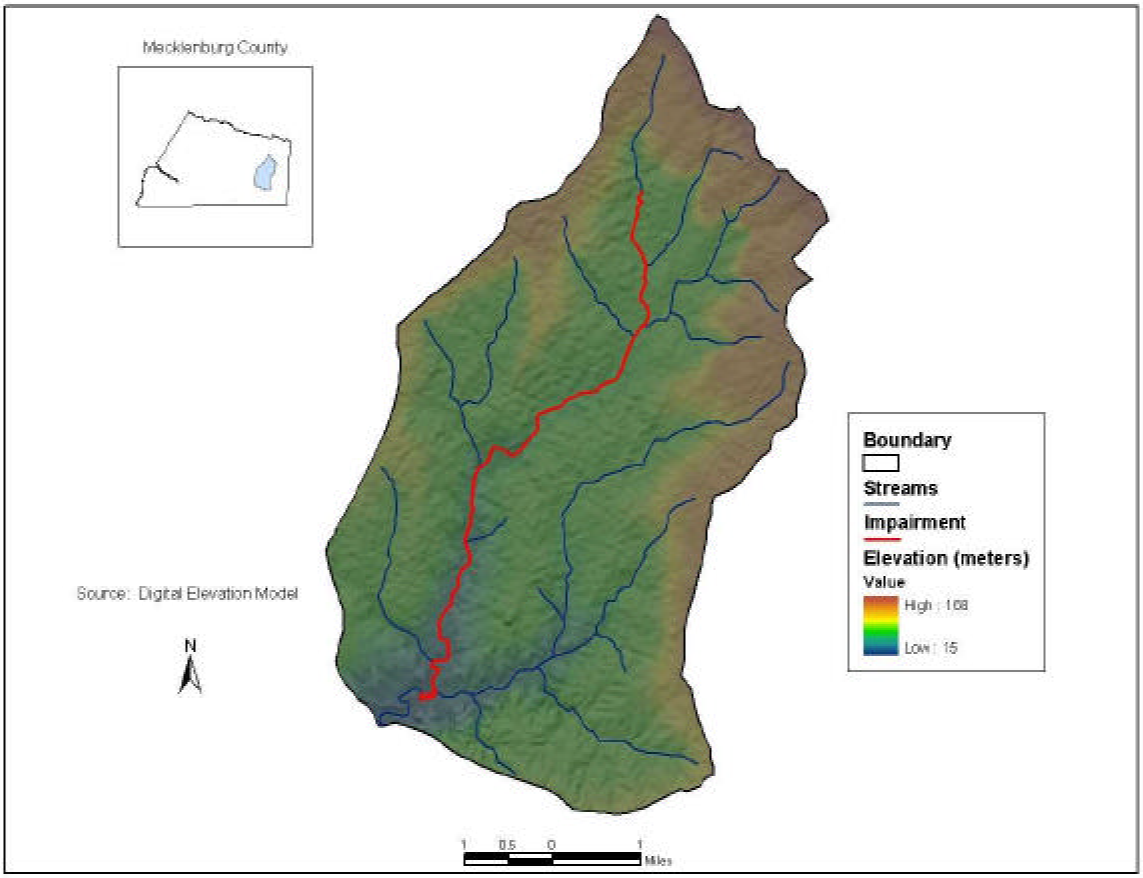
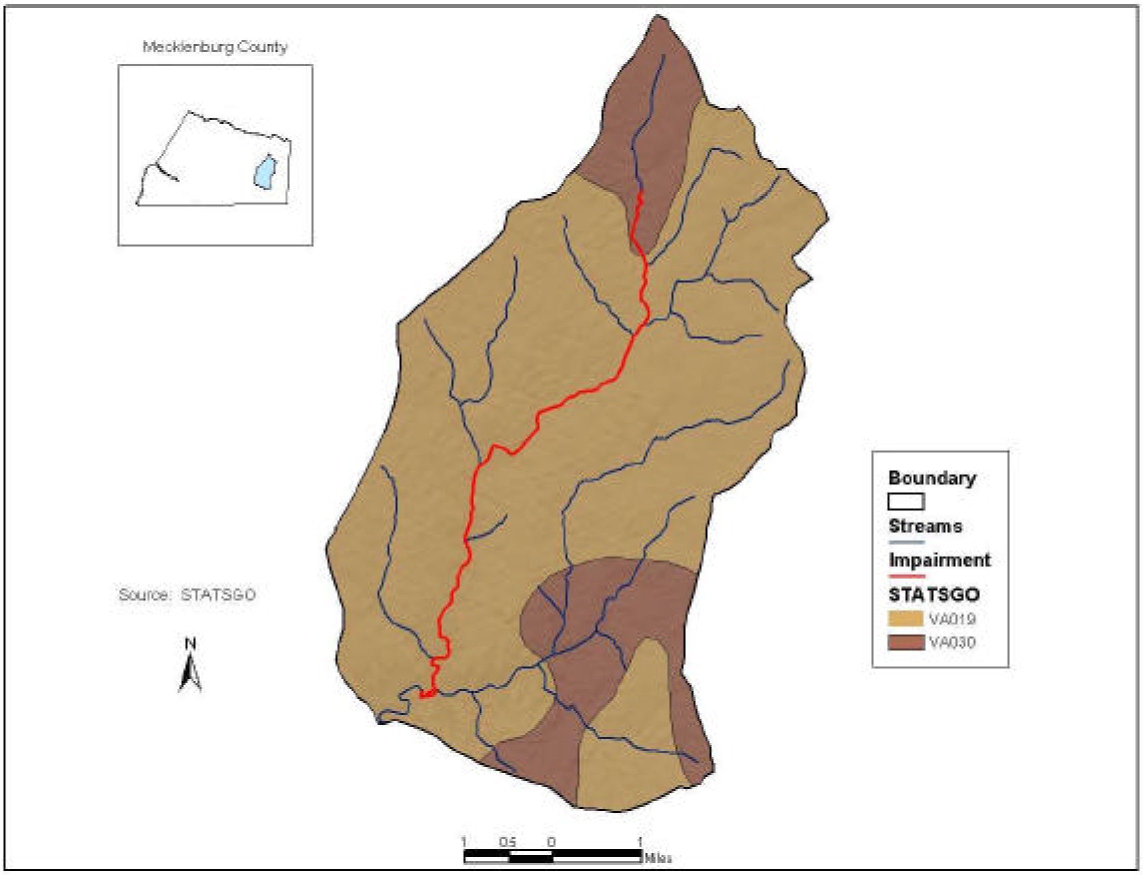



**Figure 3. Major soil groups of the Flat Creek watershed**


Mecklenburg County
Source: STATSGO
N
Boundary
Streams
Impairment
STATSGO
VA019
VA030
1
0.5
0
1
Miles

***Climate***

The drainage area of the Flat Creek watershed is approximately 29.51 square miles. The average annual rainfall as recorded at the John H. Kerr Dam, Virginia (~10.0 miles southwest of study area) is 38.55 inches. Table 2 presented below provides a summary of climate data for the John H. Kerr Dam, Virginia weather station (VA State Climatology Office, 2003).

**Table 2. Climate summary for John H. Kerr dam, Virginia (444414)**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Average Max. Temperature (F)** | 48 | 51 | 59 | 70 | 78 | 85 | 89 | 87 | 82 | 71 | 61 | 51 | 69 |
| **Average Min. Temperature (F)** | 27 | 29 | 36 | 45 | 54 | 63 | 67 | 66 | 59 | 46 | 37 | 30 | 46 |
| **Average Total Precipitation (in.)** | 3.56 | 3.19 | 4.01 | 3.20 | 3.72 | 3.44 | 4.60 | 3.91 | 3.53 | 3.41 | 3.01 | 3.04 | 38.55 |

***Land Use***

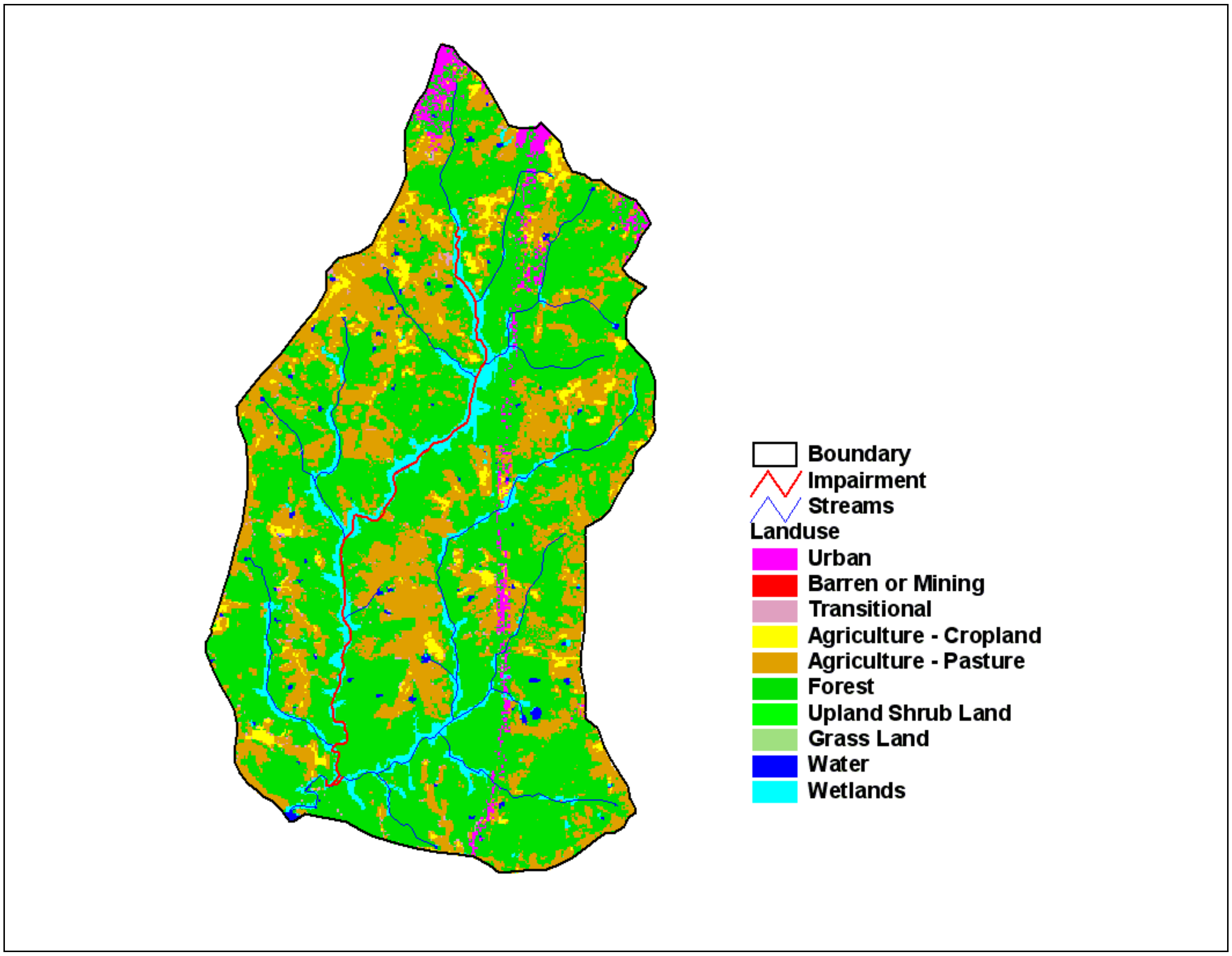
The Flat Creek watershed study area is approximately 18,917 acres, which is predominately forested (60 percent), with the majority of the remaining area in pastureland (28 percent). The remaining 12 percent of the watershed consist of residential areas, cropland, wetlands, and open water (Table 3). A map of the distribution of land use in the watershed (Figure 4) indicates that the pastureland is located throughout the watershed, with forest bordering the mainstem and tributaries of Flat Creek.

**Table 3. Land use in the Flat Creek watershed**

| Land Use Category | Area (acres) | Area (%) |
|---|---|---|
| Open Water | 118.1 | 0.62 |
| Low Intensity Residential | 236.4 | 1.25 |
| High Intensity Residential | 1.11 | 0.006 |
| High Intensity Commercial/Industrial | 148.8 | 0.79 |
| Transitional | 130.3 | 0.69 |
| Deciduous Forest | 5607 | 29.6 |
| Evergreen Forest | 3052 | 16.1 |
| Mixed Forest | 2703 | 14.3 |
| Pasture/Hay | 5260 | 27.8 |
| Row Crops | 557.1 | 2.94 |
| Other Grasses | 4.23 | 0.02 |
| Woody Wetlands | 1048 | 5.54 |
| Emergent Herbaceous Wetlands | 50.26 | 0.27 |
| Total | | 100.00 |

Source: Virginia National Land Cover Data (NLCD) Version 05-27-99

**Figure 4. Land Use in the Flat Creek Watershed**




## 3. Description of Water Quality Problem/Impairment

Flat Creek was listed as impaired on Virginia's 1996 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1996), 1998 303(d) TMDL List and Report (VADEQ, 1998), and 2002 303(d) Report on Impaired Waters (VADEQ, 2002) due to violations of the State's water quality standard for fecal coliform bacteria. Out of 24 samples collected during the 1996 assessment period, 7 violated the water quality standard at station 4AFLT008.79. During the most recent 2002 assessment period, 12 of 57 samples violated the standard at station 4AFLT008.79. Station 4AFLT008.79 complete sampling record is highlighted in Table 4. Time series fecal coliform data and seasonal fecal coliform data may be found in figures 6 and 7, respectively.

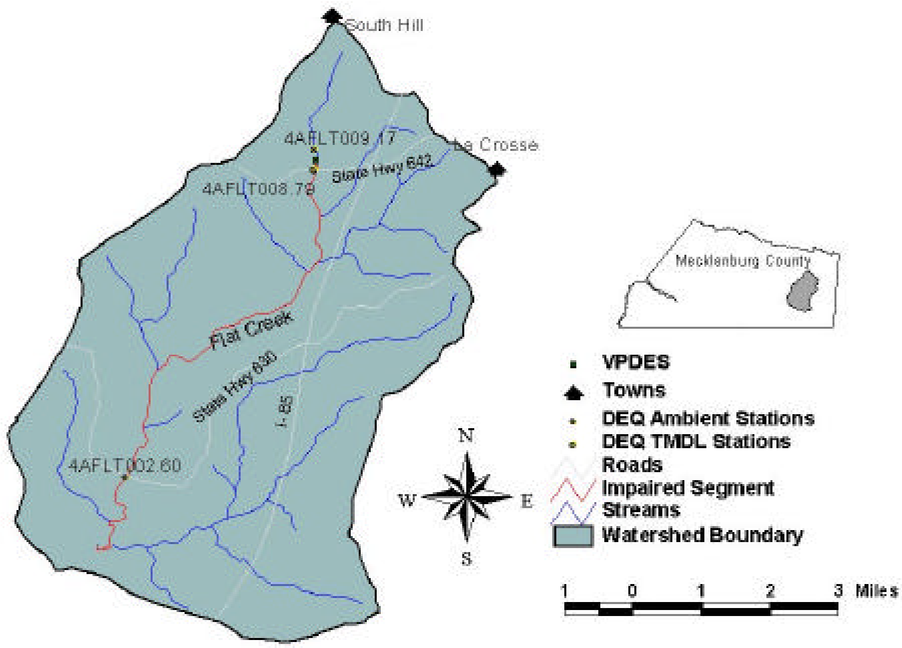
Table 4 presents a summary of all of the fecal coliform data collected by DEQ on Flat Creek. The data collected shows periodic violations since the 1970's. There have been improvements in the watershed over the last several years; however the listing station is still exceeding water quality standards. The listing station for the current water quality impairment is 4AFLT008.79, which is depicted in the watershed map below (Figure 5).

**Table 4. Fecal coliform data collected by DEQ on Flat Creek**

| Station | Date of First Sample | Date of Last Sample | Number of Samples | Average (cfu/100 ml) | Minimum (cfu/100 ml) | Maximum (cfu/100 ml) | Number of Exceed-ances* |
|---|---|---|---|---|---|---|---|
| 4AFLT001.10 | 6/18/1971 | 09/04/1990 | 42 | 850 | 100 | 8000 | 7 |
| 4AFLT002.60 | 10/06/2003 | 10/06/2003 | 1 | 150 | 150 | 150 | 0 |
| 4AFLT008.79 | 08/19/1975 | 09/23/2003 | 139 | 1485 | 18 | 16000 | 31 |
| 4AFLT008.80 | 01/29/2002 | 09/23/2003 | 4 | 92 | 18 | 220 | 0 |
| **1996 303(d) Data (April 1,1993 to March 31, 1995)** | | | | | | | |
| 4AFLT008.79 | 04/01/1993 | 03/31/1995 | 24 | 2105 | 100 | 16000 | 6 |
| **1998 303(d) Data (July 1, 1992 to June 30, 1997)** | | | | | | | |
| 4AFLT008.79 | 07/01/1992 | 06/30/1997 | 59 | 2150 | 18 | 16000 | 17 |
| **2002 303(d) Data (January 1, 1996 to December 31, 2000)** | | | | | | | |
| 4AFLT008.79 | 01/01/1996 | 12/31/2000 | 57 | 1434 | 18 | 16000 | 12 |

* Exceedances of the then-applicable instantaneous standard of 1,000 cfu/100 mL

**Figure 5. Map of Flat Creek watershed**




A time series graph of the data collected at station 4AFLT008.79 from 1991 until 2003 is presented as Figure 6. The horizontal line at the 1000 cfu/100 ml mark represents the then-applicable instantaneous fecal coliform water quality standard. The data points above the 1000 cfu/100 ml line illustrate violations of the water quality standard.

**Figure 6. Time series of fecal coliform concentrations (station 4AFLT008.79) from May 1990 to January 2004.**

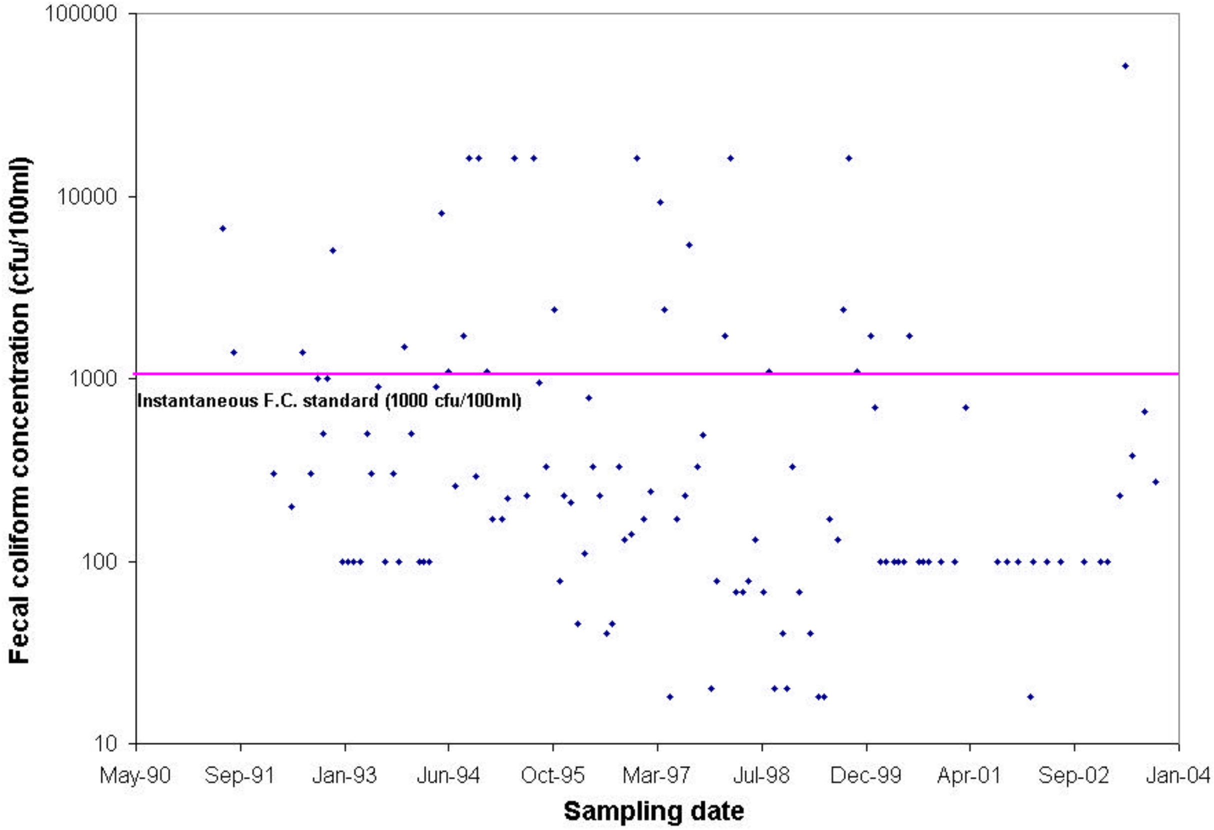
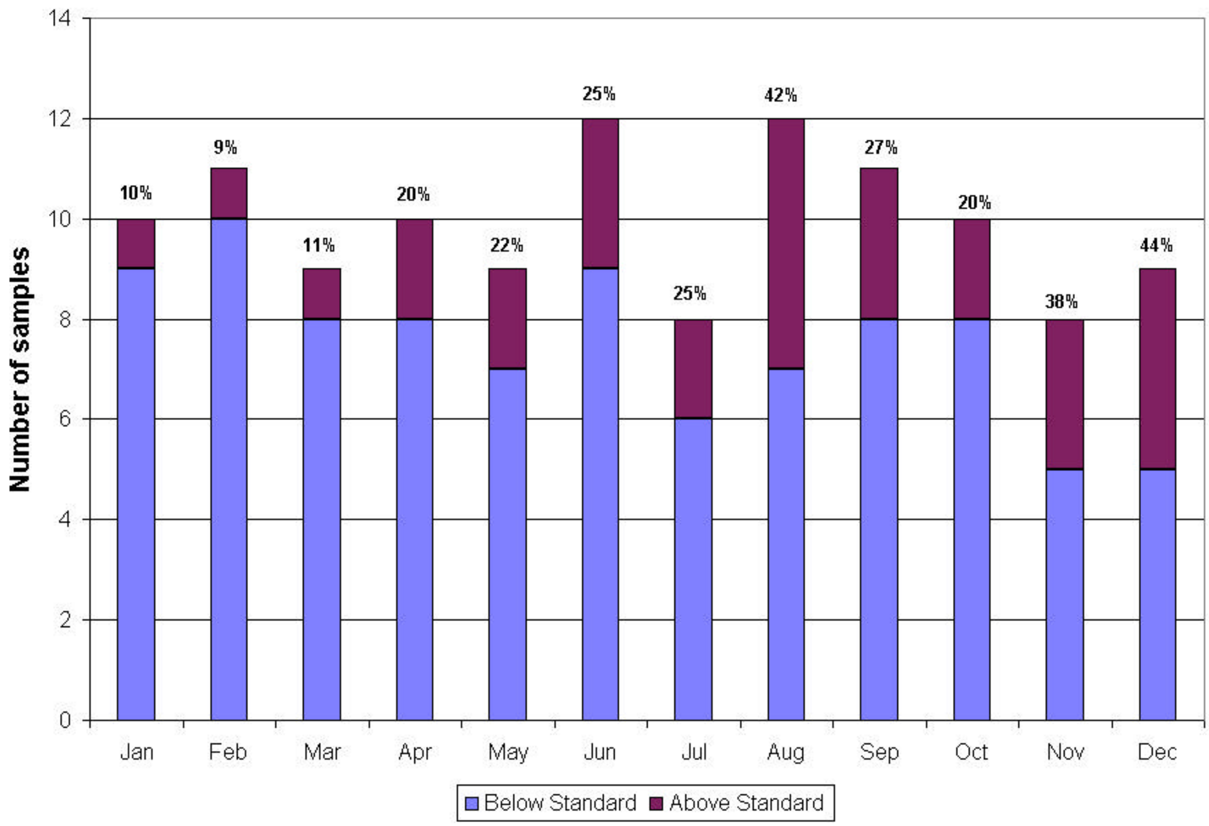



Figure 7 presents the distribution of water samples and exceedances (instantaneous fecal water quality standard - 1000 cfu/100mL) by month.

**Figure 7. Distribution of fecal coliform samples and violations (station 4AFLT008.79)**




# 4. Water Quality Standard

According to Virginia Water Quality Standards (9 VAC 25-260-5), the term *"water quality standards means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.)."*

As stated above, Virginia water quality standards consist of a designated use or uses and water quality criteria. These two parts of the applicable water quality standard are presented in the sections that follow.

## *4.1. Designated Uses*

According to Virginia Water Quality Standards (9 VAC 25-260-10A), *"all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)."*

As stated above, Flat Creek must support all designated uses and meet all applicable criteria.

### *4.2. Applicable Water Quality Criteria*

The applicable water quality criteria for bacteria in the Flat Creek watershed have changed since the initial listing on the 303(d) report. Following EPA recommendations, the Virginia Department of Environmental Quality (DEQ) proposed more stringent fecal coliform bacteria standards as well as new standards for *Escherichia coli* (*E. coli*) bacteria. These new standards were adopted by the State Water Control Board in May 2002, public noticed in June 2002, approved by the USEPA in November 2002, and were effective January 15, 2003.

The EPA recommendation that states adopt *E. coli* and enterococci (saltwater) standards stems from a stronger correlation between the concentration of *E. coli* and enterococci organisms and the incidence of gastrointestinal illness. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. *E. coli* is a subset of the fecal coliform group; thus a waterbody listed as impaired for fecal coliform is considered to be listed for *E. coli* as well.

Although Flat Creek was listed as impaired due to a violation of the previous fecal coliform standard, the TMDL must be developed to meet the new *E. coli* bacteria standard. The interim fecal coliform bacteria standard presented below will not apply to this TMDL since 12 *E. coli* bacteria samples were collected as part of the bacteria source tracking study of the source assessment.

*New Bacteria Standards*

For a non-shellfish supporting water body such as Flat Creek to be in compliance with Virginia bacteria standards for primary contact recreational use, the DEQ specifies the following criteria (9 VAC 25-260-170):

*1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*

*2. E. coli and enterococci bacteria per 100 ml of water shall not exceed the following:*

**Table 5. Applicable water quality standards**

| Parameter | Geometric Mean[1] (cfu/100 ml) | Single Sample (cfu/100 ml) |
|---|---|---|
| *E. coli* (fresh water) | 126 | 235 |
| Enterococci (saltwater & Transition Zone 3) | 35 | 104 |

[1] for two or more samples taken during a calendar month.

If the waterbody exceeded either criterion more than 10% of the time, the waterbody was classified as impaired and the development and implementation of a TMDL was indicated in order to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion was applied to a particular datum or data set (9 VAC 25-260-170). If the sampling frequency was one sample or less per 30 days, the instantaneous criterion was applied; for a higher sampling frequency, the geometric criterion was applied. These were the criteria used for listing the impairments included in this study. Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported.

For Flat Creek, the TMDL is required to meet the instantaneous criterion since the load-duration approach used to develop the TMDL for Flat Creek yields the maximum allowable bacteria concentration under any given flow condition. Unlike a continuous time series simulation, the flow duration approach does not yield daily bacteria concentrations, which are needed to apply the geometric mean standard. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect bacteria loading.

# 5. Assessment of Bacteria Sources

The assessment bacteria sources in traditional bacteria TMDL studies involves estimating loads from sources in the watershed and developing a computer model to establish the links between estimated loads and actual in-stream bacteria concentrations.

In a load-duration, bacteria TMDL, source assessment is accomplished by determining the relative contribution by source of the fecal bacteria contained in a sample of stream water. This method of source identification is achieved through microbial source tracking (MST). MST methods that specifically use bacteria as the target organism are referred to collectively as bacteria source tracking (BST) methods. MST has been applied to study microbial ecology of environmental systems for years and are now being applied to help improve water quality by identifying problem sources and determining the effect of implemented remedial solutions. Management and remediation of water pollution would be more cost effective if the correct sources could be identified (Simpson, 2002).

To support BST analyses in load-duration TMDLs, bacteria loading in a watershed is also estimated. These load estimates are broken into point and non-point sources. It is important to note that the non-point source load estimates represent loading to the surface of the watershed; they are not estimates of in-stream loads.

The following sections present BST analysis and point- and non-point source load estimates.

## *5.1. Bacteria Source Tracking (BST)*

**Background**

MST methods can be divided into three categories: molecular (genotype), biochemical (phenotype), and chemical. Molecular methods may offer the most precise identification of specific types of sources but are limited by high per-isolate costs and detailed and time-consuming procedures. They are not yet suitable for assaying large numbers of samples in a reasonable time frame. Biochemical methods (BST) may or may not be as precise, but are more simple, quicker, less costly, and allow large numbers of samples to be assayed in a short period of time (Hagedorn, 2002).

Several biochemical BST methods are in various stages of development. Among these are Antibiotic Resistance Analysis (ARA), F-Specific (F+ or FRNA) Coliphage, Sterols or Fatty Acid Analysis, Nutritional Patterns, and Fecal Bacteria Ratios. Of these, ARA has been chosen as the BST method for this TMDL report.

The ARA method uses fecal streptococcus (including the enterococci) and/or *E. coli* and patterns of antibiotic resistance for separation of sources. The premise is that human fecal bacteria will have the greatest resistance to antibiotics and that domestic and wildlife animal fecal bacteria will have significantly less resistance (but still different) to the battery of antibiotics and concentrations used. Most investigators are testing each isolate on 30 to 70+ antibiotic concentrations (Hagedorn, 2002). A more detailed description of the ARA method used by MapTech, Inc. in support of this TMDL is presented in Appendix B.

**BST Sampling and Results**

A total of 12 ambient water quality samples were collected by DEQ staff and submitted to MapTech, Inc. (MapTech) for BST analysis. The BST analyses performed by MapTech determined the relative contribution of overall bacteria by human, pet, livestock, and wildlife sources. Fecal and *E. coli* bacteria were also enumerated as part of the analyses performed by MapTech. Results of the Flat Creek BST sampling program are presented in Tables 6 and 7.

**Table 6. Flat Creek bacteria source tracking results, site 4AFLT008.79**

| Sample Date | Fecal Coliform (cfu) | *E. coli* (cfu) | BST Distribution | | | |
|---|---|---|---|---|---|---|
| | | | Wildlife | Human | Livestock | Pet |
| 09/12/2002 | 1800 | 15 | 0% | 13% | 62% | 25% |
| 10/07/2002 | 340 | 12 | 15% | 70% | 15% | 0% |
| 11/25/2002 | 90 | 17 | 60% | 10% | 30% | 0% |
| 12/11/2002 | 1100 | 600 | 4% | 0% | 8% | 88% |
| 01/13/2003 | 20 | 10 | 0% | 0% | 100% | 0% |
| 02/24/2003 | 40 | 13 | No viable *E. coli* isolates | | | |
| 03/31/2003 | 330 | 170 | 4% | 0% | 42% | 54% |
| 04/30/2003 | 230 | 32 | 38% | 0% | 31% | 31% |
| 05/14/2003 | 52000 | 46000 | 0% | 0% | 100% | 0% |
| 06/26/2003 | 380 | 40 | 31% | 25% | 25% | 19% |
| 08/27/2003 | 660 | 16 | 0% | 0% | 0% | 100% |
| 09/23/2003 | 270 | 520 | 38% | 0% | 62% | 0% |
| | | Average | **17%** | **11%** | **43%** | **29%** |
| | | Standard Deviation | 21% | 21% | 34% | 37% |

According to BST results, the greatest contributor E. coli to Flat Creek downstream of the South Hill STP is livestock, followed by pets.

**Table 7. Flat Creek bacteria source tracking results, site 4AFLT009.17**

| Sample Date | Fecal Coliform (cfu) | *E. coli* (cfu) | BST Distribution | | | |
|---|---|---|---|---|---|---|
| | | | Wildlife | Human | Livestock | Pet |
| 09/12/2002 | 1500 | 15 | 25% | 0% | 50% | 25% |
| 10/07/2002 | 250 | 44 | 40% | 53% | 7% | 0% |
| 11/25/2002 | 150 | 18 | 18% | 0% | 73% | 9% |
| 12/11/2002 | 1700 | 1400 | 4% | 0% | 96% | 0% |
| 01/13/2003 | 30 | 15 | 6% | 0% | 44% | 50% |
| 02/24/2003 | 90 | 48 | 33% | 0% | 0% | 67% |
| 03/31/2003 | 650 | 280 | 4% | 0% | 71% | 25% |
| 04/30/2003 | 70 | 33 | 31% | 0% | 44% | 25% |
| 05/14/2003 | 300 | 240 | 13% | 0% | 87% | 0% |
| 06/26/2003 | 210 | 92 | 4% | 4% | 92% | 0% |
| 08/27/2003 | 700 | 48 | 13% | 0% | 66% | 21% |
| 09/23/2003 | 140 | 650 | 63% | 4% | 33% | 0% |
| | | Average | **21%** | **5%** | **55%** | **19%** |
| | | Standard Deviation | 18% | 15% | 31% | 22% |

It is apparent from the BST data that livestock are the main cause of bacterial impairment in Flat Creek both upstream and downstream of the South Hill STP. Pet waste is also a large contributor to the high E. coli levels in Flat Creek at both sites.

## 5.2. Point Sources

Bacteria loading from point sources such as sewage treatment plants, small commercial establishments, schools, homes and businesses require permits under the Virginia Pollution Discharge Elimination System (VPDES) permit program. In order to consider all such point-source discharges in the Flat Creek watershed, the DEQ comprehensive environmental database, regional DEQ permit staff, and local Virginia Department of Health (VDH) offices were all queried. One bacteria point-source discharger was identified.

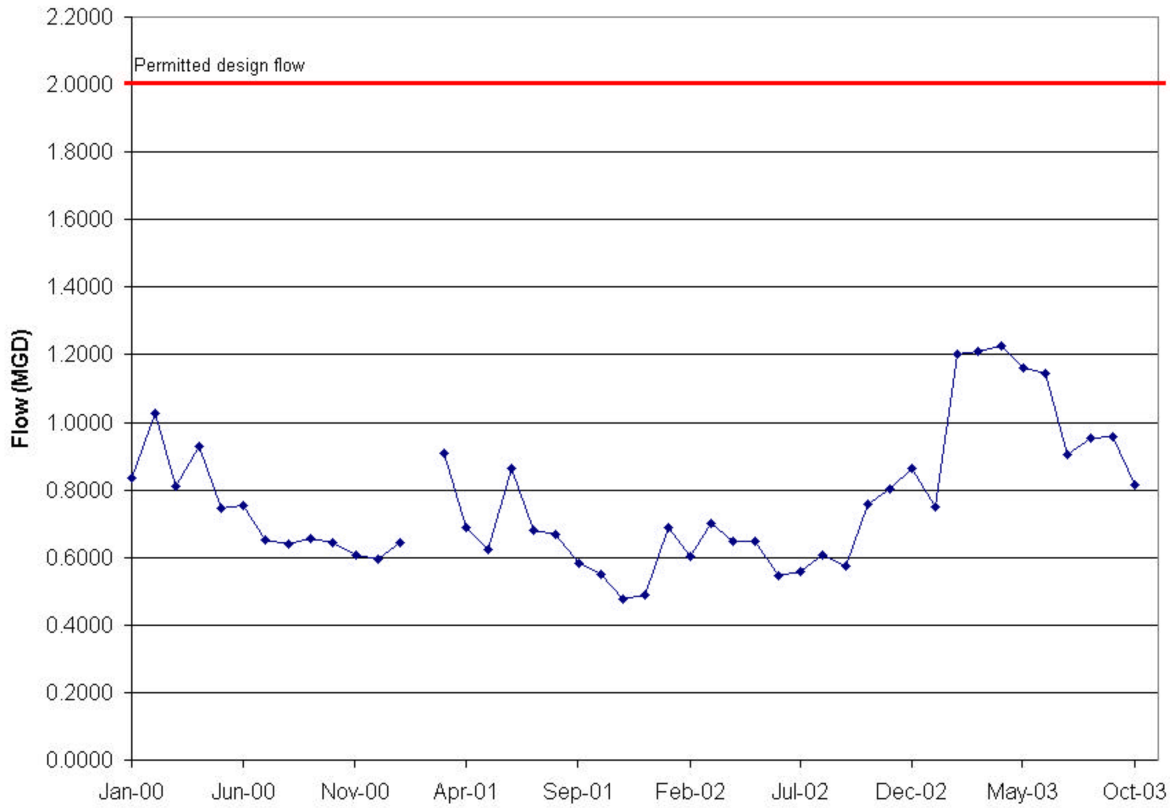
The one point source is covered under VPDES individual permits for sewage discharge for having greater than 1000 gallons per day. The permitted point source is presented in Table 8. The South Hill WWTP was upgraded over a period from 1994 to 1996 to correct malfunctions that resulted in untreated solids being discharged into Flat Creek. In addition, there have been numerous sanitary sewer overflows resulting in discharges of untreated sewage to Flat Creek and its tributaries. Figure 6 demonstrates that since the upgrades, there have been fewer violations of the instantaneous standard.

**Table 8. VPDES point source facilities and loads**

| Stream Name | Facility Name | VPDES Permit Number | Discharge Type | Design Flow (MGD) | Permitted *E. coli* Concentration (cfu/100 ml) | Permitted *E. coli* Load (cfu/yr) |
|---|---|---|---|---|---|---|
| Flat Creek | South Hill WWTP | VA0069337 | Major Municipal | 2.0 | 126 | $3.48 \times 10^{12}$ |

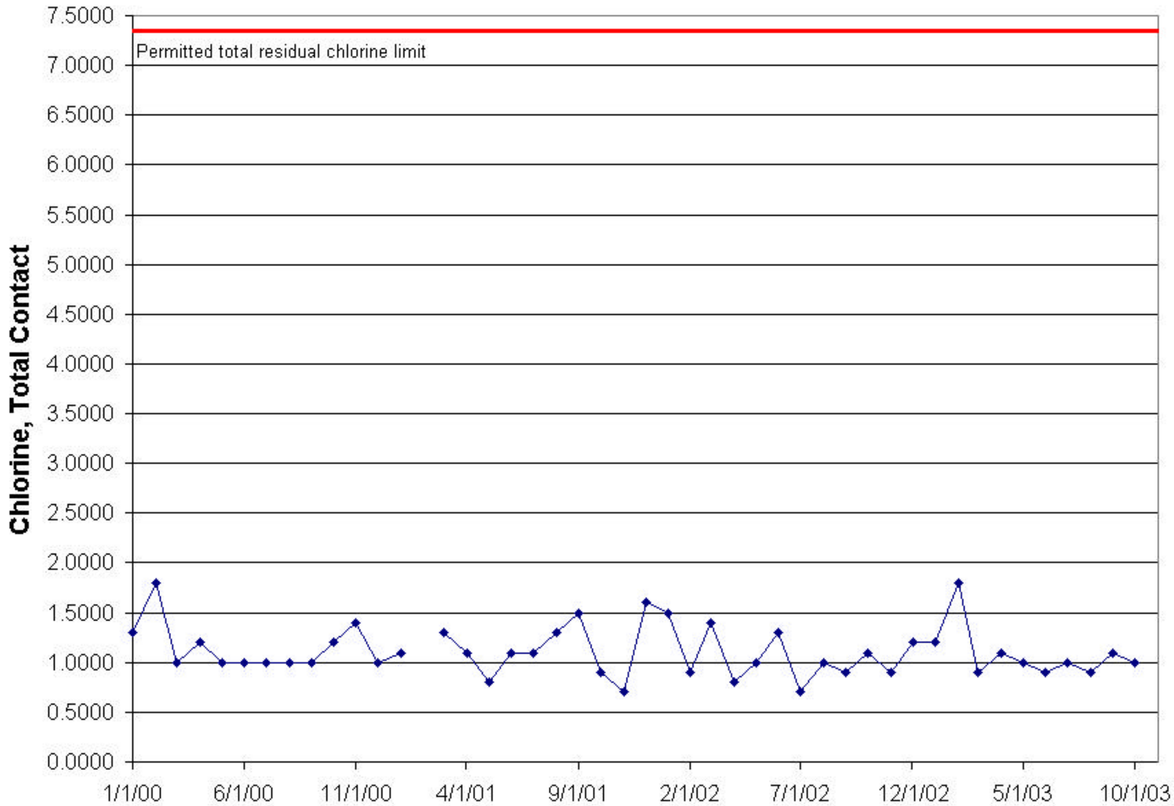
Permitted loads were calculated by multiplying the permitted discharge concentration (126 cfu/100 ml) times the design flow (2.0 MGD or 2,000,000 gal/day) times the appropriate unit conversions. The calculation is presented in Appendix C.

**Figure 8. South Hill STP Average Daily Flow from January 2000 to October 2003.**




The South Hill Sewage Treatment Plant (STP) is permitted to discharge an average of 2,000,000 gallons per day (gpd) or 2 million gallons per day (MGD). Figure 8 shows the variation of the South Hill STP flow from January 2000 until October 2003. The average daily flow ranged from 475,400 to 1,228,300 gpd (0.4754 to 1.2283 MGD). These flows are within DEQ permitted levels.

**Figure 9. South Hill STP TRC concentrations from January 2001 to October 2003**




The South Hill STP uses chlorine to disinfect wastewater. Reported residual chlorine concentrations are presented in Figure 9. Chlorine concentration data from January 2000 until October 2003 indicate that total residual chlorine (TRC) concentrations ranged from 0.7 to 1.8 mg/L. This indicates that adequate disinfection was achieved at the plant.

### *5.3. Non-Point Sources*

In order to gain an understanding of non-point source loading in the Flat Creek watershed, bacteria loads for typical non-point sources were estimated. These estimates were based upon animal and human population data sets, typical waste production rates and typical bacteria densities in waste products.

Currently published values for fecal bacteria production rates are primarily in terms of fecal coliform. There is little data on *E. coli* production; however, studies have shown that though minor variability will exist between sources, *E. coli* represents roughly 90-95% of fecal coliforms contained in "as-excreted" fecal material (Yagow, 2002). This implies that the relative bacteria contribution by source should remain constant.

It is important to note that the bacteria loads presented in the following sections on non-point sources represent "as-produced" loads. This is to say that some portion of an estimated load may not be available to be transported to Flat Creek in runoff.

#### 5.3.1. Humans and Pets

Bacteria loading from human sources can come from straight pipes, failing septic systems, and land-applied biosolids. Failing septic systems are typically manifested by effluent discharging to the ground surface where the bacteria laden effluent is then available to be washed into a stream as runoff during a precipitation event. In contrast, discharges from straight pipes are typically directly deposited to streams.

All biosolids can contain a certain concentration of fecal bacteria. When biosolids are applied to the land surface, the potential exists for a portion of these fecal bacteria to be transported to a stream as runoff during storm events.

***Sanitary Sewer Overflows***

Sanitary sewer overflows (SSOs) in South Hill result in discharges of untreated sewage to Flat Creek and its tributaries. The sewer pipes in the older sections of South Hill are made of terra cotta and are subject to breakage by tree roots and blockage by grease or other debris. The town is required to report known SSOs to the Virginia DEQ, including an estimate of the amount discharged, the discharge location, and whether the discharge entered Waters of the State. There have been four known discharges from SSOs to Flat Creek or its tributaries in 2003 totaling over 76,500 gallons. Reporting of SSOs was not tracked prior to 2003, but a file review revealed two overflows in 1997 and 1998 resulting in a total discharge of over 600 gallons to Flat Creek. A leaking sewer line located in the headwaters of Flat received a new liner in February 2004. The pipe was leaking for an unknown amount of time, therefore it may have been a primary contributor to the bacteria standards violations in Flat Creek.

***Straight Pipes***

The Southside District office of the Virginia Department of Health reported no known straight pipes in the Flat Creek Watershed.

***Septic Systems***

Based on 2000 U.S. Census data, the Flat Creek watershed is populated by approximately 892 residents living in approximately 579 households. The South Hill WWTP serves approximately 5338 residents; however, many of these residents do not live in the Flat Creek watershed. Approximately 700 of the 892 residents in the Flat Creek watershed live within the South Hill town limits and are likely connected to the WWTP. It is assumed that all remaining households are served by septic systems.

Based on the estimated population and number of households, there are an average of 1.5 people per household in the Flat Creek watershed. An estimated 467 households in the Flat Creek watershed are connected to the South Hill WWTP, and the remaining 128 households use septic systems. Assuming a wastewater production rate of 75 gallons per person per day (Geldreich, 1978) and a fecal coliform density in septic tank waste of $1.04 \times 10^{6}$ cfu per 100 mL (MapTech, 2002), the total septic load in the Flat Creek watershed is estimated to be $2.07 \times 10^{14}$ cfu per year. Of this total septic load, only the load from failing septic systems would be available as runoff.

Septic system failure rates depend largely on the age of the septic system. Surveys of failing septic systems in other Virginia watersheds have yielded a formula for calculating a rate of septic system failures for a given area. At septic system failure rates of 5% to 15%, the septic loading available as runoff to Flat Creek could vary from as low as $1.04 \times 10^{13}$ cfu/yr to as high as $3.11 \times 10^{13}$ cfu/yr.

***Biosolids***

In the Commonwealth of Virginia, the VDH and the DEQ regulate biosolids generation and application to the land surface. The DEQ regulates the generation of biosolids and the land application of those biosolids <u>by the generator</u>. The VDH regulates contractors who transport and spread biosolids; the biosolids can be from in-state or out-of-state sources.

The DEQ comprehensive environmental database was queried for biosolids application permits in the Flat Creek watershed. No permits for the application of biosolids were found.

***Pets***

The number of pets in the watershed was estimated based on the number of households. Assuming an average of 1.7 dogs and 2.1 cats per household (National Pet Owner Survey, American Pet Products Manufacturers Association, 2001-2002), the estimated pet population in the Flat Creek watershed consists of 984 dogs and 1216 cats. Using the waste production rates and fecal coliform densities from MapTech, 2002, the total bacteria loads from dogs and cats in the Flat Creek watershed are 7.76 x $10^{13}$ and 7.75 x 107 cfu per year, respectively. Table 9 presents the calculation of human and pet loads in the watershed. It should be noted that the numbers presented in Table 9 represent loads available for runoff and not in-stream loads.

**Table 9. Estimated fecal coliform production from humans and pets in the Flat Creek watershed**

| Source | Population | Waste Production Rate | Waste Fecal Coliform Density | Total Est. Annual Fecal Production |
|---|---|---|---|---|
| Failing Septic Systems | 10% x 128 systems x 1.5 people/system = 19.2 people | 75 gal/day/person x 37.85412 100mL/gal x 365 days/yr = 1.04 x $10^6$ 100mL/yr/person * | 1.04 x $10^6$ cfu/100mL * | 2.07 x $10^{13}$ cfu/yr |
| Dogs | 984 dogs | 450 g/dog/day ** | 4.8 x $10^5$ cfu/g ** | 7.76 x $10^{13}$ cfu/yr |
| Cats | 1216 cats | 19.4 g/cat/day ** | 9 cfu/g ** | 7.75 x $10^7$ cfu/yr |

* Geldreich, 1978. A conversion factor of 37.85412 was used to convert gallons to 100mL.

** MapTech, 2002 (Gills Creek TMDL Report).

## 5.3.2. Livestock

Fecal matter from livestock can be deposited directly to the stream in instances where livestock have stream access, or the fecal matter can be transported to the stream in surface runoff from grazing or pasture lands.

The predominant types of livestock in the Flat Creek watershed are cattle, although all types of livestock were considered in developing the TMDL. 1997 Census of Agriculture data for Mecklenburg County were used to estimate the livestock population in the watershed (http://govinfo.library.orst.edu/php/agri/area.php). The Flat Creek watershed is located entirely within Mecklenburg County and contains approximately 4.94% of the total pastureland in the county as determined by GIS analysis. Table 10 presents the livestock population estimates, fecal production rates, and estimated annual fecal loads in the watershed. It should be noted that the numbers presented in Table 10 represent loads available for runoff and not in-stream loads.

**Table 10. Estimated annual fecal coliform production from livestock in the Flat Creek watershed**

| Source | Population* | | Waste Production Rate** (lbs/animal/day) | Fecal Density** (cfu/g) | Total Fecal Production*** (cfu/yr) |
|---|---|---|---|---|---|
| | Mecklenburg County | Flat Creek | | | |
| Beef Cows | 13,823 | 500 | 46.4 | $1.01 \times 10^5$ | $3.88 \times 10^{14}$ |
| Milk Cows | 1,593 | 0 | 120.4 | $2.58 \times 10^5$ | 0 |
| Hogs | NA**** | NA**** | 11.3 | NA**** | NA**** |
| Sheep | NA**** | NA**** | 2.4 | NA**** | NA**** |
| Horses | 415 | 50 | 51.0 | $9.40 \times 10^4$ | $3.97 \times 10^{13}$ |

* The livestock population in the Flat Creek watershed was estimated using information obtained from local citizens.

** MapTech, 2002.

*** A conversion factor of 453.6 was used to convert pounds to grams.

**** Withheld to avoid disclosing data for individual farms.

### 5.3.3. Wildlife

Like livestock, fecal matter from wildlife can be either deposited directly to the stream, or it can be transported to the stream in surface runoff from woods, pastureland and cropland. Direct deposition to streams varies with species, e.g. beaver spend most of their time in water; therefore most of their fecal matter would be directly deposited to the stream.

Wildlife populations in the Flat Creek watershed were estimated based on wildlife densities used in developing TMDLs in Pittsylvania and Halifax Counties (Table 11). The use of the Pittsylvania and Halifax County wildlife densities was deemed appropriate by the Department of Game and Inland Fisheries (Marc Puckett, 2003). Habitat was assigned as follows:

- deer: all land use categories
- turkey: deciduous forest, evergreen forest, mixed forest
- muskrat: woody wetlands, emergent herbaceous wetlands, open water
- beaver: stream miles
- raccoon: low intensity residential, deciduous forest, evergreen forest, mixed forest, woody wetlands, row crops
- goose: pasture/hay, row crops, emergent herbaceous wetlands, open water
- mallard: woody wetlands, emergent herbaceous wetlands, open water

**Table 11. Estimated fecal coliform production from wildlife in the Flat Creek watershed**

| Source | Population Density[1] | Habitat | Watershed Population (animals) | Range of Waste Production Rate (cfu/an/day) | | Range or Fecal Coliform Production(cfu/yr) | |
|---|---|---|---|---|---|---|---|
| | | | | *Low* | *High* | *Low* | *High* |
| Deer | 0.031 an/ac | 18916.91 ac | 586 | $1.52 \times 10^8$ | $3.60 \times 10^8$ | $3.25 \times 10^{13}$ | $7.70 \times 10^{13}$ |
| Turkey | 0.010 an/ac | 11361.93 ac | 114 | $9.3 \times 10^7$ | | $3.87 \times 10^{12}$ | |
| Muskrat | 2.751 an/ac | 1216.5 ac | 3347 | $2.50 \text{ X } 10^7$ | $1.90 \text{ X } 10^8$ | $3.05 \times 10^{13}$ | $2.32 \times 10^{14}$ |
| Beaver | 4.800 an/mi | 41 mi | 197 | $3.00 \times 10^6$ | | $2.16 \times 10^{11}$ | |
| Raccoon | 0.070 an/ac | 7360.2 ac | 515 | $2.05 \times 10^7$ | $9.45 \text{ X } 10^8$ | $3.85 \times 10^{12}$ | $1.78 \times 10^{14}$ |
| Goose | 0.004 an/ac | 5985.1 ac | 24 | $5.87 \times 10^4$ | $2.25 \times 10^9$ | $5.14 \times 10^8$ | $1.97 \times 10^{13}$ |
| Mallard | 0.002 an/ac | 1216.5 ac | 2 | $2.43 \times 10^9$ | | $1.77 \times 10^{12}$ | |
| Total | | | | | | $7.27 \times 10^{13}$ | $5.13 \times 10^{14}$ |

[1]Marc Puckett, VADGIF, 2003

# 6. TMDL Development

One of the major obstacles to improving stream water quality is that the potential sources of bacteria are numerous and the dominant sources and/or pathways are generally unknown. This can make it difficult to direct effective cleanup efforts.

Typical pathogen TMDLs are completed by developing watershed-based computer simulations that establish links between sources and in-stream water quality. While effective, the effort required to develop modeled TMDLs can be costly. In an effort to complete pathogen TMDLs in a timely and cost-effective manner, the use of load-duration analyses has been investigated. It has been determined that the load-duration method of calculating a TMDL produces a result only slightly more conservative than if the TMDL had been determined through computer modeling.

The load duration method essentially uses an entire stream flow record to provide insight into the flow conditions under which exceedances of the water quality standard occur. Exceedances that occur under low flow conditions are generally attributed to loads delivered directly to the stream such as straight pipes and livestock with access to the stream. Exceedances that occur under high flow conditions are typically attributed to loads that are delivered to the stream in stormwater runoff. Exceedances occurring under during normal flows can be attributed to a combination of runoff and direct deposits.

The following sections detail the development of the load-duration TMDL and associated allocations.

## *6.1. Load-Duration Curve*

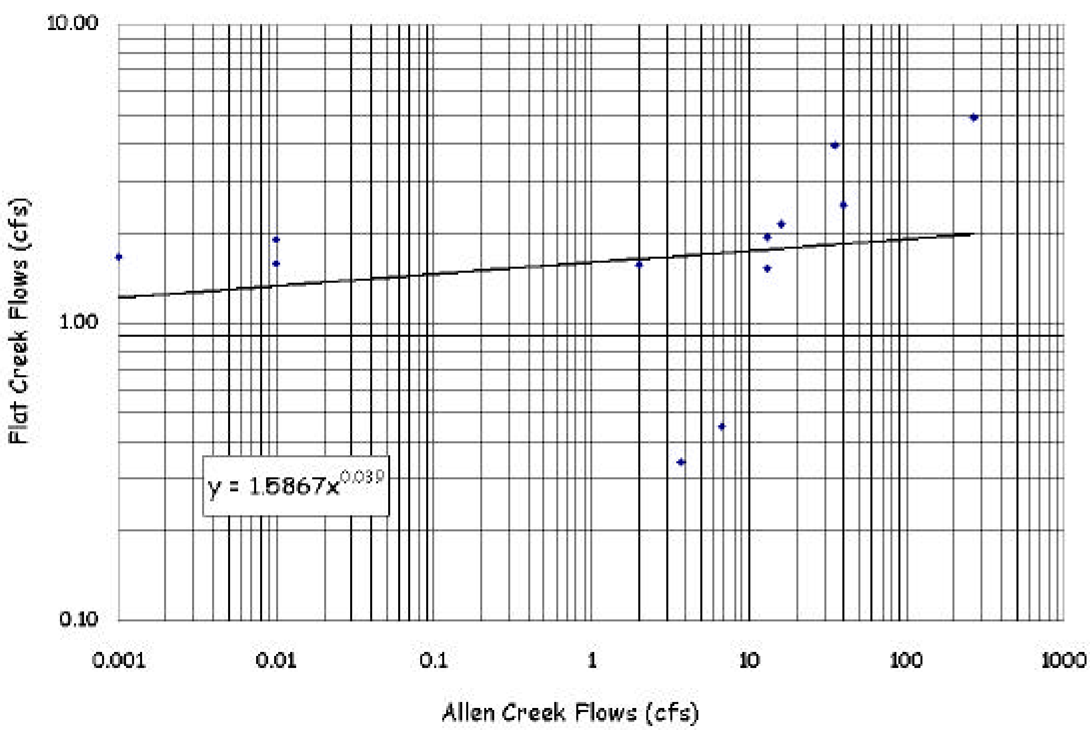
Development of a load-duration curve begins with a flow-duration curve, and in order to develop a meaningful flow-duration curve one must have several years of flow data for the target stream or river. Where very little flow data exists for a target stream, a reference stream with the requisite flow measurements must be used similar to the paired watershed approach used in watershed-based modeling. Due to the lack of a stream gage on Flat Creek, data from the stream gage on Allen Creek near Boydton, Virginia, were used as a reference.

The following sections detail the flow data for Flat Creek, the development of a flow-duration curve for Flat Creek, and the creation of a load-duration curve for Flat Creek.

### 6.1.1. Flow Data

No flow gage was located on Flat Creek, therefore Allen Creek was selected as the reference stream based on proximity and its high correlation (R-value of 0.77). The Allen Creek gauge is approximately 15 miles southwest of the Flat Creek listing station. The Allen and Flat Creek watersheds are both similar in size with Allen Creek draining an area of approximately 53.4 square miles and Flat Creek draining an area of approximately 29.6 square miles. The USGS stream gage # 02079640 on Allen Creek has 40 years of published data, from October 1, 1961 to October 2, 2003, including daily average flow measurements. This stream gage is located on Allen Creek at the U.S. Route 58 bridge near Boydton, Virginia. See Appendix D for additional information. The flow-regression curve for Flat Creek and Allen Creek is presented in Figure 10.

**Figure 10. Flow-regression curve for Flat Creek (AFLT008.79) using reference gage on Allen Creek near Boydton, VA (USGS #2079640)**




### 6.1.2. Flow-Duration Curves

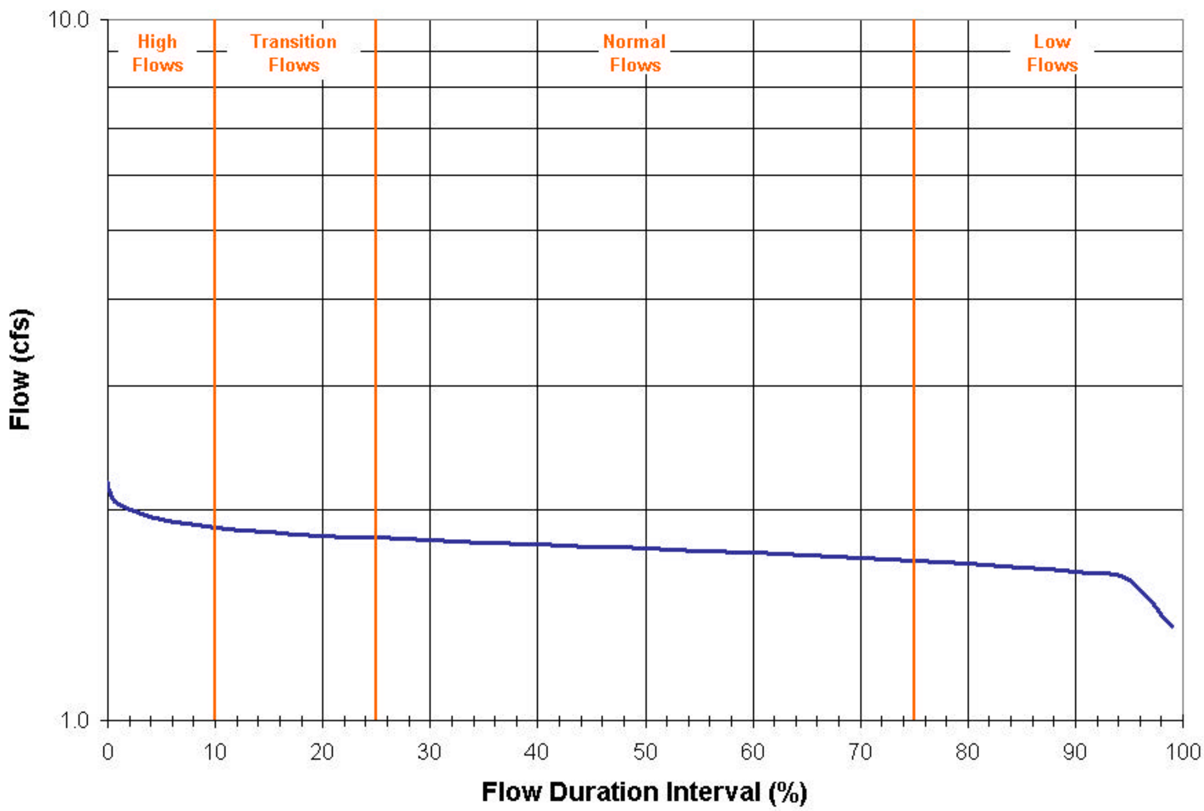
In order to use the load-duration method to develop a TMDL, a flow-duration curve must be developed for the impaired stream. This is accomplished by first developing a flow-duration curve for the reference.

A flow-duration curve is a plot showing the flow magnitude (cfs) along the "y" axis and the frequency of daily average stream flow (%) along the "x" axis. For example, the flow value corresponding to “1%” is the flow that has been exceeded only 1% of the time for which measurements exist. Likewise, the flow value corresponding to “30%” is the flow that 30% of the historic record exceeds.

To plot the flow values for the period of record of the reference stream, the PERCENTILE statistic function of Excel was used. The resulting percentile of a given flow was then subtracted from 1 to yield the percent of time that a given flow is exceeded by the flows of record. The flow duration interval values were plotted with the corresponding flows to yield a log/normal flow duration curve. The flow-duration curve for Flat Creek is presented as Figure 11.

The flow-duration curve for Flat Creek has been divided into four sections to help illustrate flow conditions. These sections are titled "High Flows", "Transition Flows", "Normal Flows", and "Low Flows". Low flows can be roughly equated to near-drought or drought flows. High flows are near-flood or flood flows. Transition flows are, as implied, neither normal nor high.

**Figure 11. Flow-duration curve for Flat Creek (AFLT008.79) using reference gage on Allen Creek near Boydton, VA (USGS #2079640)**



### 6.1.3. Load-Duration Curve

As mentioned in Section 3, the violations of the bacteria water quality standards on Flat Creek were collected at Station 4AFLT008.79. The USGS flow station used to correlate flow data to Flat Creek was located on Allen Creek near Boydton, Virginia.

A load-duration curve is developed by multiplying each flow level along the flow-duration curve by the applicable water quality standard and required unit conversions. The resulting curve represents the maximum allowable load at each flow level, in other words, the Total Maximum Daily Load (TMDL). Each water quality observation is then assigned to a flow interval by comparing the date of each water quality observation to the flow record of the reference stream. The reference stream flow from the date of the water quality observation is then used to calculate a stream flow and flow-duration interval for the target stream. Since the TMDL and required reductions must be in terms of an average annual stream flow, the loads on the load-duration curve are multiplied by 365 days/year and presented as annual loads.

In order to plot existing fecal coliform (FC) data against the *E. coli* (EC) standard/TMDL line, it was necessary to translate the FC data to EC data. Translation of FC data to EC data was achieved by using a translator equation developed from a regression analysis of 493 paired FC/EC data sets from the DEQ's statewide monitoring network. The translator equation resulting from the regression analysis is presented below:

$$\mathbf{EC\ log_2 = -0.0172 + 0.91905 * FC\ log_2}$$

By plotting these observed loads on the load-duration curve, the number and pattern of exceedances of the water quality standard (TMDL) can be analyzed. The load duration curve and observed data for Flat Creek are shown in Figure 12. The TMDL line has been plotted for the instantaneous *E. coli* standard of 235 cfu/100mL.

**Figure 12. Load duration curve and observed data for Flat Creek at station 4AFLT008.79**

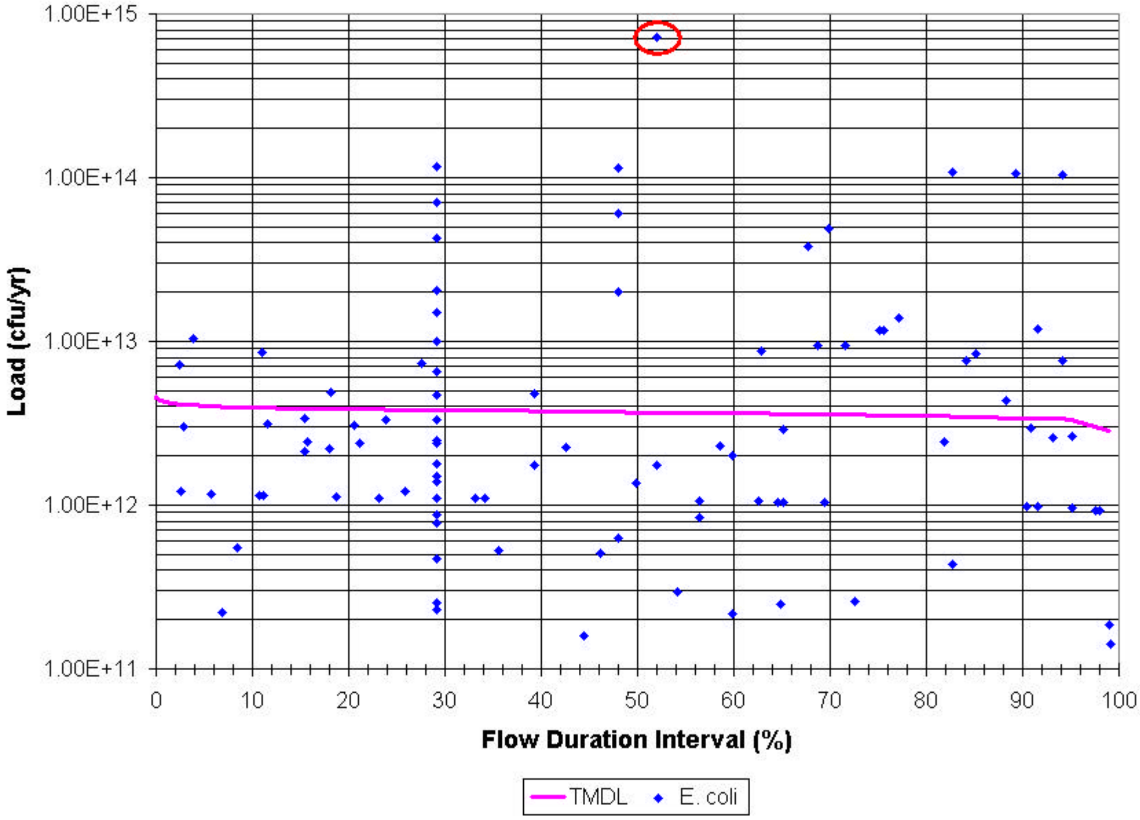
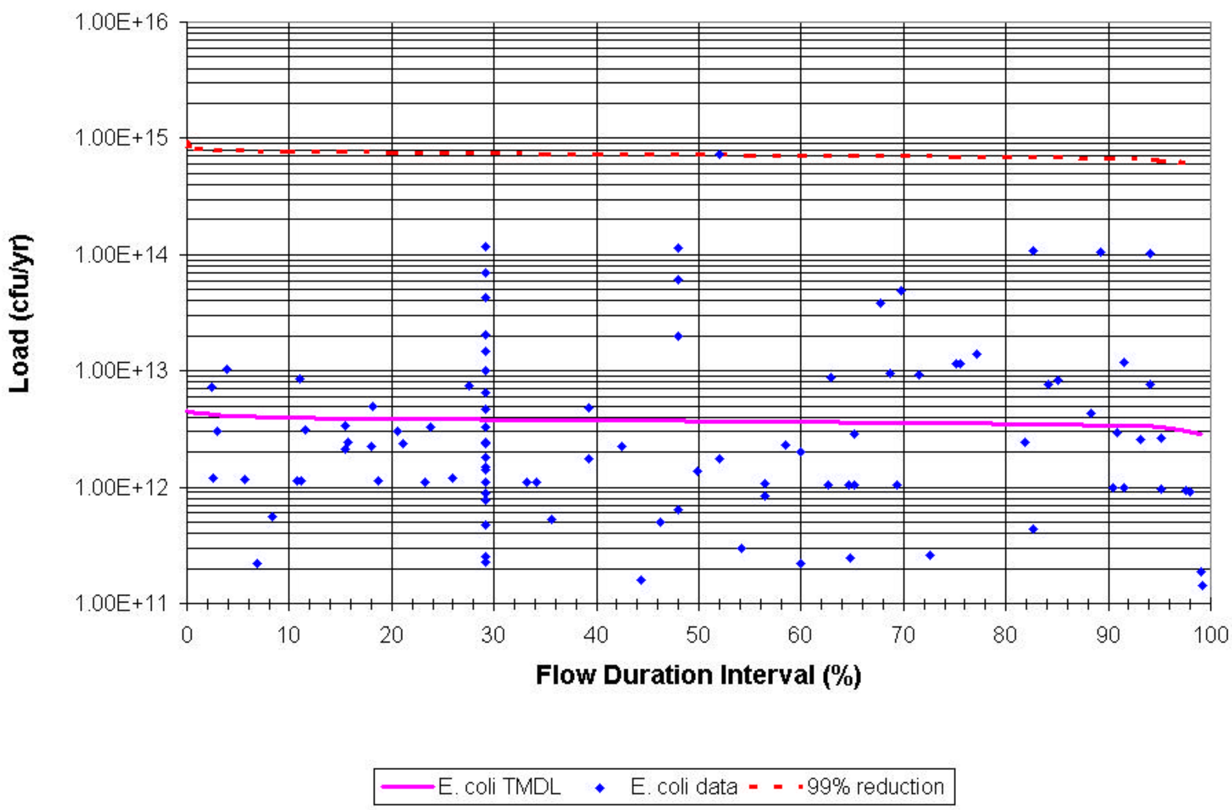



Figure 12 suggests that exceedances of the water quality standard occur under high, normal and low flow conditions. The highest exceedance of the water quality standard (circled) occurs at a normal flow that has been exceeded approximately 52% of the time (~2 cfs). This represents the flow condition under which the largest bacteria reduction is required in order to meet water quality standards. The translated load at this flow condition is 7.24 x $10^{14}$ cfu/yr. Under the instantaneous *E. coli* standard of 235 cfu/100mL, this load would have to be reduced by 99.5% to an allowable load of 3.70 x $10^{12}$ cfu/yr. The allowable load is simply the *E. coli* standard multiplied by the applicable flow condition and the proper unit conversions. The full calculation with unit conversions is presented in Appendix C.

In order to determine the necessary load reduction at the average annual flow condition, a second curve must be drawn through the highest exceedance described above. The second curve represents the magnitude of the highest observed exceedance if it were to occur over any flow condition. The graph of the load-duration curve with the max-exceedance curve is presented in Figure 13.

**Figure 13. Load duration curve with max exceedance curve for Flat Creek at station 4AFLT008.79**




## 6.2. TMDL

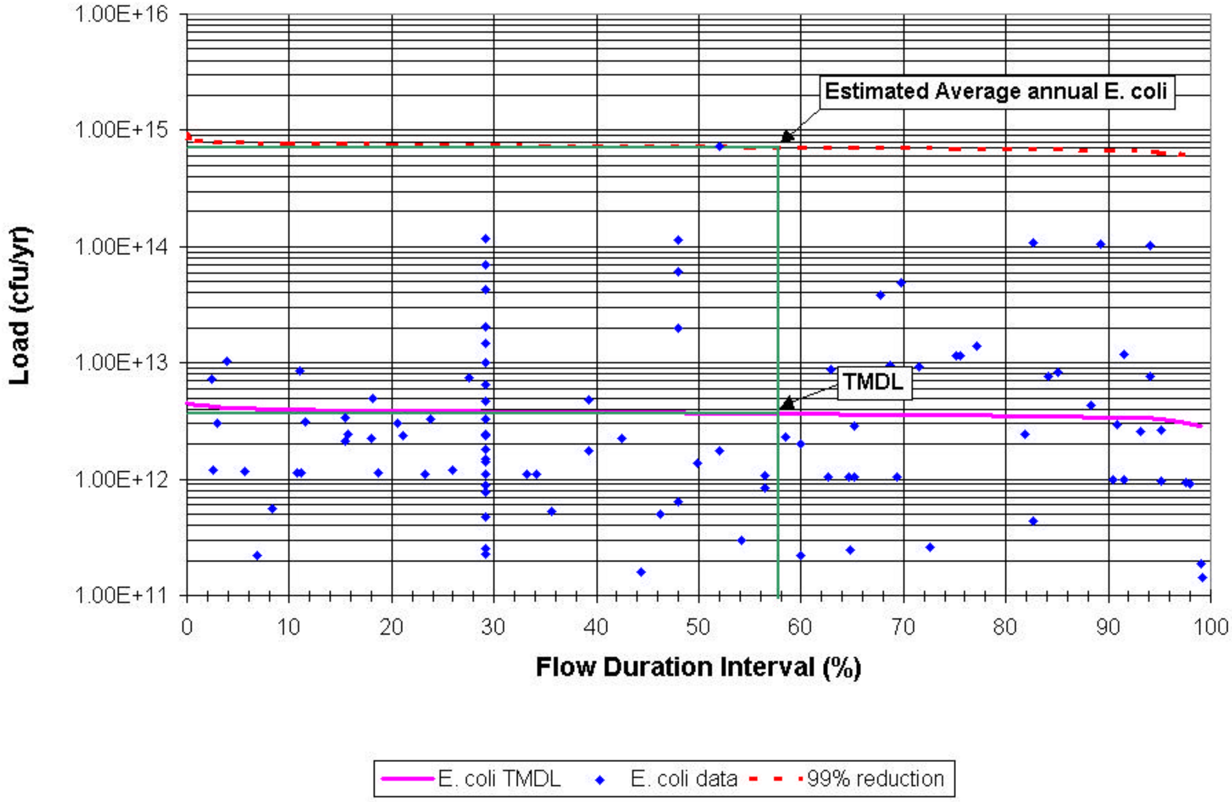
A Total Maximum Daily Load (TMDL) consists of 1) point source/waste load allocations (WLAs), 2) non-point sources/load allocations (LAs) where the non-point sources include natural/background levels, and 3) a margin of safety (MOS) where the margin of safety may be implicitly or explicitly defined. This TMDL definition is typically illustrated by the following equation:

*TMDL = WLAs + LAs + MOS*

Simply put, a TMDL is the amount of a pollutant that can be present in a waterbody where the waterbody will still meet water quality standards for that pollutant. In the case of load-duration bacteria TMDLs, the TMDL is expressed as the total number of colony forming units (cfu) per year as opposed to cfu/day. This is because the load-duration TMDL must be based on the average annual flow condition.

The average annual flow for Flat Creek is calculated from the average annual flow from the USGS stream gage (#2079640) on Allen Creek near Boydton, Virginia. The estimated average annual flow for Flat Creek is 1.75 cfs. This flow value has an associated flow duration of 57.8%. From this information an average annual *E. coli* load and TMDL can be calculated from the max-exceedance and TMDL curves. This is represented graphically in Figure 14. The full calculation is presented in Appendix C.

**Figure 14. Load duration curve illustrating the TMDL and estimated average annual *E. Coli* load for Flat Creek at station 4AFLT008.79**




The average annual *E. coli* load is 7.17 x $10^{14}$ cfu/yr, and the TMDL under average annual flow conditions is 3.66 x $10^{12}$ cfu/yr. These values are used to calculate required reductions. By subtracting the waste load allocation (known value) from the TMDL (as determined above), the load allocation can be determined. These three values are presented in Table 12.

**Table 12. Average annual *E. coli* loads and TMDL for Flat Creek watershed (cfu/yr)**

| WLA[1] | LA | MOS | TMDL |
|---|---|---|---|
| 3.48 x $10^{12}$ | 1.8 x $10^{11}$ | (implicit) | **3.66 x $10^{12}$** |

[1] The point source permitted to discharge in the Flat Creek watershed is presented in section 5.2.

# 7. Allocations

### Reduction

The annual average TMDL and *E. coli* load values from section 6.2, together with the waste load allocation from the one permitted bacteria source in section 5.2, were applied to Table 13 to determine the required reduction. Since the required reduction will only apply to the non-point sources, the LA value was used to calculate the required percent reduction. The full calculations are presented in Appendix C.

**Table 13. TMDL and required reduction for Flat Creek**

| Allowable Loads (cfu/yr) | | Average Annual EC Load (cfu/yr) | Required Reduction |
|---|---|---|---|
| Waste Load Allocation (WLA) | $3.48 \times 10^{12}$ | | |
| Load Allocation (LA) | $1.8 \times 10^{11}$ | $7.1352 \times 10^{14}$ | |
| MOS | (implicit) | | |
| **TMDL (annual average)** | **$3.66 \times 10^{12}$** | **$7.17 \times 10^{14}$** | **99.5%** |

As illustrated in Table 13, the WLA for the Flat Creek watershed has a considerable effect on the LA reduction calculations.

**Margin of Safety**

This requirement is intended to add a level of safety to account for any inherent uncertainty in the TMDL development process and the data used in the development. The MOS may be either implicit or explicit. An implicit margin of safety relies on the conservative nature of the assumptions, values, and methods used to calculate a TMDL whereas an explicit margin of safety is a value (typically a percentage) applied at some point during the TMDL calculation.

In the Flat Creek TMDL, an implicit MOS was incorporated through the use of conservative analytical assumptions. These include: (1) the use of the single-most extreme water quality violation event which was used to develop maximum exceedance curve over the entire range of flow conditions, and (2) the computation of average annual load using the average flow conditions. Additionally, the load duration method of TMDL development has been evaluated against TMDLs that were developed using computer modeling. The results showed the load duration method to be slightly more conservative.

**Allocations**

In order to apply the reduction calculated above, the average annual *E. coli* load had to be allocated to each of the four non-point sources identified in the BST analysis. Table 14 shows the distribution of the average annual *E. coli* load among sources, the reduction applied to each source, and the allowable loading for each source.

**Table 14. Average annual non-point source load distribution, reduction, and allowable load by source**

| | Total (cfu/yr) | Human @ 11% (cfu/yr) | Pet @ 29% (cfu/yr) | Livestock @ 43% (cfu/yr) | Wildlife @ 17% (cfu/yr) |
|---|---|---|---|---|---|
| **Average Annual Load** | **$7.1352 \times 10^{14}$** | **$7.85 \times 10^{13}$** | **$2.07 \times 10^{14}$** | **$3.07 \times 10^{14}$** | **$1.21 \times 10^{14}$** |
| **Reduction** | 99.975% | 99.975% | 99.975% | 99.975% | 99.975% |
| **Allowable Annual Load** | **$1.8 \times 10^{11}$** | **$1.96 \times 10^{10}$** | **$5.175 \times 10^{10}$** | **$7.675 \times 10^{10}$** | **$3.03 \times 10^{10}$** |

## *7.1. Consideration of Critical Conditions*

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Flat Creek is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken to meet water quality standards. The sources of bacteria for Flat Creek are a mixture of dry and wet weather driven sources. TMDL development utilizing the load-duration approach applies to the full range of flow conditions; therefore, the critical conditions for Flat Creek were addressed during TMDL development.

## *7.2. Consideration of Seasonal Variations*

Seasonal variations involve changes in stream flow and water quality as a result of hydrologic and climatological patterns. The load-duration approach allows the pattern of water quality exceedances to be examined for seasonal variations. The load-duration method used to develop this TMDL implicitly incorporates the seasonal variations of precipitation and runoff by looking at the highest water quality violation and applying it to the entire stream flow record when calculating the TMDL.

# 8. Implementation and Reasonable Assurance

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on the South Mayo River. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent “TMDL Implementation Plan Guidance Manual”, published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

## 8.1. TMDL Implementation Process

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

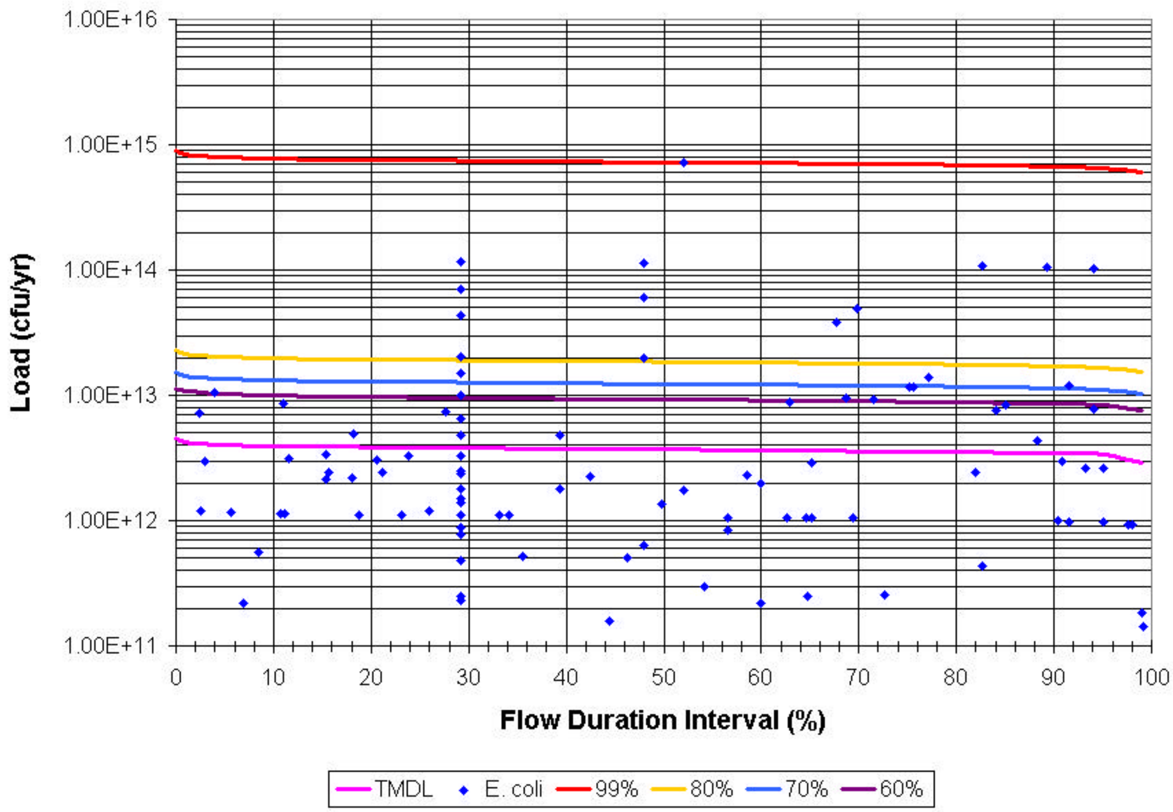
1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

## 8.2. Stage I Implementation Goal

As stated in Section 7.0 the TMDL requires a 99.975% reduction in non-point source loading in order to attain a 0% violation of water quality standards. In order to evaluate interim reduction goals for a phased implementation plan, several reduction levels and their associated violation rates were assessed. Reduction curves similar to the max exceedance/reduction curve of Figure 13 were plotted on the Flat Creek load-duration curve. These reduction curves are presented in Figure 15.

As part of the Stage I reduction goal, the Town of South Hill will aggressively monitor and immediately repair leaking or blocked sewer lines. In addition, the town will be regularly updating sewer lines as funds become available. If the Stage I goal of halting SSOs does not result in attainment of water quality standards, then other non-point sources of bacteria will be reduced by the required amount of 99.975%.

**Figure 15. Load duration curve illustrating the TMDL and reduction curves for Flat Creek at station 4AFLT008.79**




The theoretical violation rates for the various load reductions presented in Figure 14 are presented below in Table 15.

**Table 15. Load Reductions and WQS Violation Rates**

| Load Reduction | Violation Rate |
|---|---|
| 99.975% | 0% |
| 80% | 10% |
| 70% | 13% |
| 60% | 17% |

Based on the reduction analysis presented above and a goal of 10% or fewer violations of the water quality standard, a suitable Phase I management reduction level would be 70%. Table 16 presents the Phase I load allocations based on a 70% reduction of in-stream loads.

**Table 16. Phase I Load Allocations for a Management scenario (based on a 70% reduction)**

| | Total (cfu/yr) | Human (cfu/yr) | Pet (cfu/yr) | Livestock (cfu/yr) | Wildlife (cfu/yr) |
|---|---|---|---|---|---|
| **Average Annual Load** | **$7.1352 \times 10^{14}$** | **$7.85 \times 10^{13}$** | **$2.07 \times 10^{14}$** | **$3.07 \times 10^{14}$** | **$1.21 \times 10^{14}$** |
| **Reduction** | 70% | 98% | 77% | 82% | 0% |
| **Allowable Annual Load** | $2.14 \times 10^{14}$ | $1.57 \times 10^{12}$ | $4.761 \times 10^{13}$ | $5.526 \times 10^{13}$ | $1.21 \times 10^{14}$ |

A violation rate scenario on the reduction analysis presented above and a goal of 10% or fewer violations of the water quality standard was also calculated. Table 17 presents the Phase I load allocations based on an 80% reduction of in-stream loads.

**Table 17. Phase I Load Allocations for a violation rate scenario (based on an 80% reduction)**

| | Total (cfu/yr) | Human (cfu/yr) | Pet (cfu/yr) | Livestock (cfu/yr) | Wildlife (cfu/yr) |
|---|---|---|---|---|---|
| **Average Annual Load** | **$7.1352 \times 10^{14}$** | **$7.85 \times 10^{13}$** | **$2.07 \times 10^{14}$** | **$3.07 \times 10^{14}$** | **$1.21 \times 10^{14}$** |
| **Reduction** | 80% | 99% | 99% | 89% | 0% |
| **Allowable Annual Load** | $1.43 \times 10^{14}$ | $7.85 \times 10^{11}$ | $2.07 \times 10^{12}$ | $3.38 \times 10^{13}$ | $1.21 \times 10^{14}$ |

In order to provide some insight into the nature of the Flat Creek water quality violations and to better target possible BMPs, the correlation between violations and local precipitation was examined.

Results indicate that approximately 59% of the violations occurred during times of or just after a precipitation event. This suggests that those violations could be related to runoff events. The complete analysis is presented in Appendix E.

BMPs effective in correcting dry weather/low-flow violations of the bacteria water quality standard typically include streamside fencing for cattle exclusion, straight pipe replacement, and septic system repair. Among some of the BMPs effective in reducing bacteria runoff from precipitation events include riparian buffers zone, retention ponds/basins, range and pasture management, and animal waste management. Detailed lists of BMPs and their relative effectiveness will be presented in the eventual TMDL implementation plan for the Flat Creek watershed.

## *8.3. Link to Ongoing Restoration Efforts*

No Best Management Practices (BMPs) have been implemented in the Flat Creek watershed. No current BMPs have been implemented and there are no known plans to implement BMPs in the future. Current available BMP monies are limited in the watershed. VDEQ and Lake Country SWCD believe additional grants monies through the TMDL program would be greatly beneficial to reach members of the community that have not participated in BMP programs.

## *8.4. Reasonable Assurance for Implementation*

### 8.4.1. Follow-Up Monitoring

VADEQ will continue to monitor Flat Creek in accordance with its ambient monitoring program. The ambient trend station to be monitored is 4AFLT002.60. VADEQ and VADCR will continue to use data from the trend station on Flat Creek to evaluate reductions in bacteria counts and the effectiveness of the TMDL in attainment of water quality standards. Ambient sampling includes field parameters (temperature, pH, dissolved oxygen, conductivity), bacteria, nutrients and solids. Future bacteria sampling will consist of *E. coli* sampling only, since the interim fecal coliform bacteria will be phased out after twelve *E. coli* samples have been collected.

### 8.4.2. Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

### 8.4.3. Implementation Funding Sources

A key factor in implementing TMDLs is funding. One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Non-point Source Management Program. Watershed restoration activities, such as TMDL implementation, are eligible for Section 319 funding. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement Program (CREP) and Environmental Quality Incentive Programs (EQIP), the Virginia State Revolving Loan Program, and the VA Water Quality Improvement Fund (WQIP). The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

### 8.4.4. Wildlife Contributions and Water Quality Standards

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia has proposed (during its recent triennial water quality standards review) a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria will become effective pending EPA approval and can be found at http://www.deq.state.va.us/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for non-point source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.state.va.us/wqs/WQS03AUG.pdf.

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in section 8.1 above. DEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

# 9. Public Participation

The development of the Flat Creek TMDL would not have been possible without public participation. A public meeting was held at the R. T. Arnold Library located at 110 E. Danville Street in South Hill, Virginia on October 20, 2003 to discuss the process for TMDL development and the source assessment input. Twelve people attended the meeting. Copies of the presentation materials were available for public distribution. The meeting was public noticed in the Virginia Register. There was a 30 day-public comment period and no written comments were received.

A second public meeting was held at the R. T. Arnold Library located at 110 E. Danville Street in South Hill, Virginia on March 16, 2004 to discuss the results of the TMDL development and the source assessment. Nineteen people attended the meeting. Copies of the presentation materials were available for public distribution. The meeting was public noticed in the Virginia Register. There was a 30 day-public comment period and no written comments were received.

# 10. References

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# Appendix A: Glossary

## GLOSSARY

**Note: All entries in italics are taken from USEPA (1998). All non-italicized entries are taken from MapTech (2002).**

**303(d).** A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

***Allocations.*** *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (non-point or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future non-point source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

***Ambient water quality.*** *Natural concentration of water quality constituents prior to mixing of either point or non-point source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

***Anthropogenic.*** *Pertains to the [environmental] influence of human activities.*

***Antidegradation Policies.*** *Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

***Background levels.*** *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

***Bacteria.*** *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

**Bacterial source tracking (BST).** A collection of scientific methods used to track sources of fecal contamination.

***Best management practices (BMPs).*** *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally non-point source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

**Biosolids.** Biologically treated solids originating from municipal wastewater treatment plants.

***Clean Water Act (CWA).*** *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is section 303(d), which establishes the TMDL program.*

***Concentration.*** *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

***Concentration-based limit.*** *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

**Confluence.** The point at which a river and its tributary flow together.

***Contamination.*** *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

***Cost-share program.*** *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

***Critical condition.*** *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

***Designated uses.*** *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

***Dilution.*** *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

***Direct runoff.*** *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

***Discharge.*** *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

***Discharge permits (under NPDES).*** *A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established* *under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

**DNA.** Deoxyribonucleic acid. The genetic material of cells and some viruses.

***Domestic wastewater.*** *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

***Drainage basin.*** *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

***Effluent.*** *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

***Effluent limitation.*** *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

***Endpoint.*** *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

***Existing use.*** *Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).*

**Fecal Coliform.** Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

***Feedlot.*** *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

**Geometric mean.** A measure of the central tendency of a data set that minimizes the effects of extreme values.

**GIS.** Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

***Ground water.*** *The supply of fresh water found beneath the earth's surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

***Hydrograph.*** *A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

***Hydrologic cycle.*** *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

***Hydrology.*** *The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

***Indicator.*** *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

***Indicator organism.*** *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

***In situ.*** *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

**Isolate.** An inbreeding biological population that is isolated from similar populations by physical or other means.

**Limits (upper and lower).** The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

***Loading, Load, Loading rate.*** *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

***Load allocation (LA).*** *The portion of a receiving waters loading capacity attributed either to one of its existing or future non-point sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and non-point source loads should be distinguished (40 CFR 130.2(g)).*

***Loading capacity (LC).*** *The greatest amount of loading a water can receive without violating water quality standards.*

***Margin of safety (MOS).*** *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the* *receiving waterbody (CWA section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

***Mathematical model.*** *A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.*

**Mean.** The sum of the values in a data set divided by the number of values in the data set.
**MGD.** Million gallons per day. A unit of water flow, whether discharge or withdraw.

***Monitoring.*** *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

***Narrative criteria.*** *Nonquantitative guidelines that describe the desired water quality goals.*

***National Pollutant Discharge Elimination System (NPDES).*** *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

***Natural waters.*** *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

***Non-point source.*** *Pollution that originates from multiple sources over a relatively large area. Non-point sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

***Numeric targets.*** *A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

***Organic matter.*** *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

***Peak runoff.*** *The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

***Permit.*** *An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

***Phased approach.*** *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when non-point sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

***Point source.*** *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

***Pollutant.*** *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

***Pollution.*** *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

***Privately owned treatment works.*** *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

***Public comment period.*** *The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a Federal Register notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

***Publicly owned treatment works (POTW).*** *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

***Raw sewage.*** *Untreated municipal sewage.*

***Receiving waters.*** *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

***Restoration.*** *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

***Riparian areas.*** *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

***Riparian zone.*** *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

***Runoff.*** *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

***Septic system.*** *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

***Sewer.*** *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

***Slope.*** *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

**Stakeholder.** Any person with a vested interest in the TMDL development.

**Standard.** In reference to water quality (e.g. 200 cfu/100 ml geometric mean limit).

***Storm runoff.*** *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

***Streamflow.*** *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

***Stream restoration.*** *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

***Surface area.*** *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

***Surface runoff.*** *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of non-point source pollutants.*

***Surface water.*** *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

***Topography.*** *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

***Total Maximum Daily Load (TMDL).*** *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for non-point sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

***Transport of pollutants (in water).*** *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

***Tributary.*** *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

**Variance.** A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

**DACS.** Department of Agriculture and Consumer Services.

**DCR.** Department of Conservation and Recreation.

**DEQ.** Virginia Department of Environmental Quality.

**VDH.** Virginia Department of Health.

***Wasteload allocation (WLA).*** *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

***Wastewater.*** *Usually refers to effluent from a sewage treatment plant. See also* ***Domestic wastewater****.*

***Wastewater treatment.*** *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

***Water quality.*** *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

***Water quality criteria.*** *Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

***Water quality standard.*** *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

***Watershed.*** *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

**WQIA.** Water Quality Improvement Act.

# Appendix B: Antibiotic Resistance Analysis (MapTech)

When performing ARA, isolates (colonies picked from membrane filtration plates) of *E. coli* or *Enterococcus* are transferred to a 96-well tissue culture plate (one isolate per well) containing a selective liquid medium. The 96-well plates are incubated and confirmed as *E. coli* or *Enterococcus* by color changes in the liquid after incubation (Figure 1). Antibiotic stock solutions are prepared and each of twenty-eight or more antibiotic/concentrations is added separately to flasks of autoclaved and cooled Trypticase Soy Agar (TSA) from the stock solutions to achieve the desired concentration, and then poured into sterile 15x100mm petri dishes.

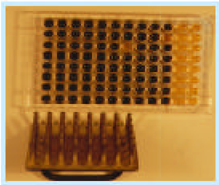

**Figure 1.** 96-well plate after incubation.

Control plates (no antibiotics) are included with each set. Isolates are transferred from the 96-well plate using a stainless steel 48-prong replica plater (Sigma). The replicator is flame-sterilized (95% ethanol) after inoculation of each TSA plate. Resistance to an antibiotic is determined by comparing each isolate to the growth of that isolate on the control plate. A one (1) is recorded for growth and a zero (0) is recorded for no growth (Figure 2). This is repeated for each isolate on each of the 30 antibiotic plates to develop a profile.

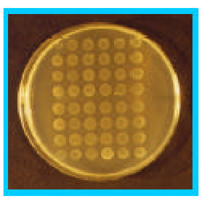

**Figure 2.** TSA control plate (with no antibiotics) showing growth of all 48 isolates.

The profile is then compared against the known source library to determine the source of the isolate (see data analysis section). The basic process is the same for all approaches, that is, a data base of known sources analyzed using the BST method of choice must be developed and samples of unknown bacterial origin are collected, analyzed and compared to the known source database. For studies, such as Total Maximum Daily Loads (TMDL), we recommend the ARA procedure due to typical cost constraints. Typically we analyze 24 isolates per unknown source (e.g. stream or well water) sample. This provides measurements of the proportion of a given source that are in increments of approximately 4%. If more precision is required, 48 isolates can be analyzed, resulting in resolution of approximately 2%. If the sampling is to be done in a geographical area where a database of known sources has not been developed, we will need to collect samples from known sources (i.e. human, livestock, wildlife) and compare them to our existing databases to determine if one of our existing databases is compatible with the study area. Twenty-four isolates from each of these samples will be analyzed. If no existing database is compatible, we will need to develop a database for the study area. The number of samples needed depend on variability of source samples. We have had a good deal of success in the past by using existing databases through obtaining known source samples from each group (i.e. human, livestock, wildlife) in the study area and comparing them to existing databases.

# Appendix C: Calculations

## Calculations

### Allowable Load Calculation from Section 5.2.

TMDL cfu/yr = Q $ft^3/s$ * 7.48 $gal/ft^3$ * 3.785 l/gal * 1000 ml/l * 235 cfu/100 ml * 60 s/min * 60 min/hour * 24 hrs/day * 365 days/yr

Where:

**TMDL cfu/yr** = Allowable load in cfu/yr
**235 cfu/100 ml** = Instantaneous *E. coli* standard
**Q $ft^3/s$** = Flow in cubic feet per second
**cfu** = *E. coli* colony forming units.
**l** = liters
**ml** = milliliters
**s** = seconds
**min** = minutes
**yr** = year
**gal** = gallons

### Required Reduction Calculation from Section 7.

TMDL cfu/yr = LA cfu/yr + WLA cfu/yr + MOS (cfu/yr)

OL = LA cfu/yr + WLA cfu/yr

% reduction = [(OL - TMDL)/OL] * 100

Where:

TMDL = total maximum daily load
LA = load allocation
WLA = waste load allocation
MOS = margin of safety
OL = observed load (average annual load)

# Appendix D: Reference Stream Selection

Once several possible reference watersheds are selected, a correlation analysis is performed on the flow measurements of the reference and target gauges. Usually the reference gauge with the strongest correlation to the target gauge is selected; however, the final decision is subject to best professional judgement. In some cases a watershed with a lower correlation may be a better choice.

The reference stream correlation is performed by entering the flow measurement data from the target stream (Flat Creek) into an Excel spreadsheet along with daily mean flow data from the reference streams. The Excel “Correlation” data analysis tool is then run to determine "R" or the Pearson's correlation coefficient which can be used as an indication of the strength of the correlation. In this analysis absolute values of the Pearson's coefficient between 0-0.19 were regarded as indicating a very weak correlation, 0.2-0.39 as weak, 0.40-0.59 as moderate, 0.6-0.79 as strong and 0.8-1 as a very strong correlation.

Allen Creek (R-value of 0.77) was selected as the reference stream based on proximity and its high correlation. The Allen Creek gauge is approximately 15 miles southwest of the Flat Creek station. The Allen and Flat Creek watersheds are both similar in size with Allen Creek draining an area of approximately 53.4 square miles and Flat Creek draining an area of approximately 29.6 square miles.

Using the Excel graphing package, the measurement data from Flat Creek were plotted against the corresponding daily mean flow data for the Allen Creek gauge. Excel was then used to draw a best-fit line through the data points and develop the equation for the “regression” line (Figure 7). Using the equation for the regression line, daily mean flow values from Allen Creek could be substituted into the “x” or independent variable in the equation and the flow at the Flat Creek station, the “y” or dependent variable, could be calculated.

# Appendix E: Flow Change and Precipitation Analysis

In order to better target BMPs for the Flat Creek watershed, the correlation between water quality violations, stream flow changes, and precipitation was investigated. The goal was to determine which violations might be related to runoff and which might be related to direct deposition.

As stated in Section 6.1 on flow data, there is no stream gauge in the Flat Creek watershed, so there is little historic flow data. For this reason, the continuous gauge at Allen Creek near Boydton (station 02079640) was used to develop the flow duration curve for Flat Creek. The theory being flow changes at the Allen Creek gauge, located approximately 15 miles southwest of the Flat Creek monitoring station, would reflect flow changes at the Flat Creek station. Changes in flow might, in turn, signify runoff from precipitation events; however, the correlation between flow change and violations could not be examined because the Allen Creek flow gauge was taken off line from October 1996 through September 2000.

To assess the link between precipitation events and E. coli standard violations, precipitation records from the John H. Kerr Dam, VA weather station (COOP ID 444414), located approximately 8 miles southwest of the Flat Creek watershed, were examined. Precipitation events on the day before and on the day of each violation were examined.

Results of the study are presented graphically (Figure E1) and in tabular format (Table E1) below.

**Figure E1. Precipitation and Flow Annotated WQS Violation Events (Flat Creek Watershed)**

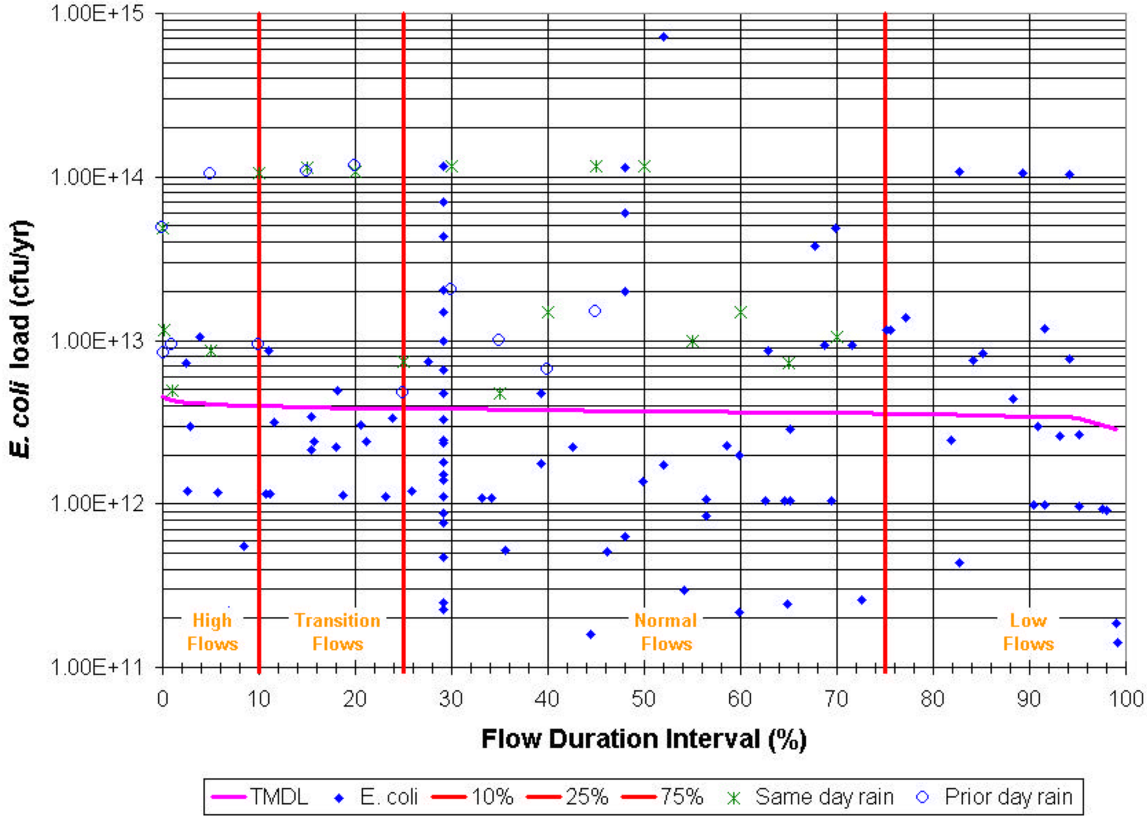

**Table E2. Water Quality Standard Violations, Stream Flow Change, and Precipitation**

| Sampling Date | Fecal Coliform (cfu/100 mL) | Translated *E. coli* Value (cfu/100 mL) | Duration Interval | *E. coli* Load (cfu/yr) | Same Day Rain (inches) | Prior Day Rain (inches) |
|---|---|---|---|---|---|---|
| 6/24/91 | 6600 | 3200 | 70 | 4.88E+13 | 0.34 | 0.02 |
| 8/20/91 | 1400 | 770 | 75 | 1.16E+13 | 0.45 | 0 |
| 7/13/92 | 1400 | 770 | 76 | 1.16E+13 | 0 | 0 |
| 9/21/92 | 1000 | 565 | 85 | 8.34E+12 | 0 | 0.16 |
| 10/20/92 | 500 | 299 | 88 | 4.37E+12 | 0 | 0 |
| 11/12/92 | 1000 | 565 | 63 | 8.72E+12 | 0 | 0 |
| 12/8/92 | 5000 | 2479 | 68 | 3.80E+13 | 0 | 0 |
| 5/17/93 | 500 | 299 | 39 | 4.77E+12 | 0 | 0 |
| 7/14/93 | 900 | 513 | 84 | 7.59E+12 | 0 | 0 |
| 11/15/93 | 1500 | 820 | 92 | 1.19E+13 | 0 | 0 |
| 12/15/93 | 500 | 299 | 18 | 4.92E+12 | 0.07 | 0 |
| 4/13/94 | 900 | 513 | 11 | 8.60E+12 | 0.01 | 0 |
| 5/12/94 | 8000 | 3819 | 48 | 6.03E+13 | 0 | 0 |
| 6/13/94 | 1100 | 617 | 72 | 9.38E+12 | 0 | 0.01 |
| 8/25/94 | 1700 | 920 | 77 | 1.38E+13 | *No data* | *No data* |
| 9/19/94 | 16000 | 7221 | 94 | 1.03E+14 | 0 | 0.07 |
| 11/7/94 | 16000 | 7221 | 89 | 1.05E+14 | 0.08 | 0 |
| 12/12/94 | 1100 | 617 | 69 | 9.43E+12 | 0 | 0.11 |
| 4/24/95 | 16000 | 7221 | 48 | 1.14E+14 | 0.51 | 0 |
| 7/26/95 | 16000 | 7221 | 83 | 1.07E+14 | 0.01 | 0.23 |
| 8/24/95 | 950 | 539 | 94 | 7.69E+12 | 0 | 0 |
| 10/30/95 | 2400 | 1263 | 48 | 1.99E+13 | 0 | 0 |
| 4/16/96 | 790 | 455 | 28 | 7.38E+12 | 0.8 | 0 |
| 12/2/96 | 16000 | 7221 | 29 | 1.17E+14 | 0.78 | 0.65 |
| 3/24/97 | 9200 | 4343 | 29 | 7.03E+13 | 0 | 0 |
| 4/15/97 | 2400 | 1263 | 29 | 2.04E+13 | 0 | 0 |
| 8/12/97 | 5400 | 2661 | 29 | 4.31E+13 | 0 | 0 |
| 10/16/97 | 490 | 293 | 29 | 4.74E+12 | 0.08 | 0.63 |
| 1/28/98 | 1700 | 920 | 29 | 1.49E+13 | 0.96 | 0 |
| 2/23/98 | 16000 | 7221 | 29 | 1.17E+14 | 0.49 | 0 |
| 8/25/98 | 1100 | 617 | 29 | 9.98E+12 | 0 | 0 |
| 8/16/99 | 2400 | 1263 | 29 | 2.04E+13 | 0 | 0.91 |
| 9/15/99 | 16000 | 7221 | 29 | 1.17E+14 | 0.21 | 0 |
| 10/21/99 | 1100 | 617 | 29 | 9.98E+12 | 0.75 | 0.34 |
| 12/27/99 | 1700 | 920 | 29 | 1.49E+13 | 0 | 0 |
| 1/19/00 | 700 | 407 | 29 | 6.59E+12 | 0 | 0.04 |
| 6/29/00 | 1700 | 920 | 29 | 1.49E+13 | 0.43 | 1.71 |
| 3/29/01 | 700 | 407 | 2 | 7.21E+12 | 0.35 | 0 |
| 12/11/02 | 600 | | 4 | 1.05E+13 | 0.23 | 0 |
| 5/14/03 | 46000 | | 52 | 7.22E+14 | 0 | 0 |
| | *E. coli* data (not transformed) | | | | | |

The results of the study suggest that as many as 23 of the 39 violations (59%) could be related to runoff events.

Additional information regarding the nature of the violation can be gleaned from looking at the flow conditions under which the violations occur. Four of the exceedances occurred during high or transitional flows. Twenty-six exceedances, including the violation requiring the highest load reduction, occurred during normal flows.  Ten exceedances occurred in the range of low flows.